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REMOTE-SENSING PRACTICE AND POTENTIAL

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REMOTE-SENSING PRACTICE AND POTENTIAL

by

A. N. Williamson, W. K. Dornbusch, W. E. Grabau

May 1974

Conducted by U. S. Army Engineer Waterways Experiment Station
Mobility and Environmental Systems Laboratory
Vicksburg, Mississippi

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Albert N. Williamson
William K. Dornbusch
Warren E. Grabau

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13. ABSTRACT

Successful use of remote sensors requires considerably more than just taking some imagery or flying an area. Six essential processes that must be accomplished if use of a remote-sensing system is to result in useful information are defined herein as problem specification, ground control data acquisition, remote-sensor information acquisition, data manipulation, information extraction, and information presentation. Identification of these processes is the result of much experience at WES in remote-sensing techniques. Several fairly common and not so common sensor types are introduced, and some devices and information extraction and presentation techniques found to be useful in remote-sensing projects are described. An overview of the current state-of-the-art of remote sensing is presented and some of the current remote-sensing capabilities of WES are introduced.

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Foreword

Over the past 15 years engineers and scientists at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., have engaged in studies directed toward using various remote-sensing instruments to gain information about ground conditions. Early investigations were directed toward development of an airborne electromagnetic sensing device for use in the study of terrain factors that affect the trafficability of soils. These studies included devices operating the microwave, visible, and infrared portions of the electromagnetic spectrum and resulted in a series of reports under the general title "Terrain Analysis by Electromagnetic Means."

At the same time studies were made to determine effects of various factors in the natural environment on the activities of man and the effects of the activities of man on his environment and to develop techniques for specifying the performance requirements of various items of materiel on the basis of the environment in which the materiel is to be operated.

This work has resulted in substantial experience in design, development, and utilization of various remote sensors; development of data acquisition, storage, retrieval, and utilization techniques; and marriage of the two into an overview of what is believed to be an effective means of using remote sensors to solve various problems.

This report presents a general overview of the state-of-the-art of remote sensing as perceived by WES and introduces some of the capabilities at WES that have been developed in connection with past projects.

Studies that have led to this report were conducted by personnel of the Mobility and Environmental Systems Laboratory (MESL), formerly Mobility and Environmental Division, and the Soils and Pavements Laboratory (SPL), formerly Soils Division. All portions of this work were under the general supervision of Mr. W. G. Shockley, Chief, MESL, Mr. W. J. Turnbull, former Chief of the Soils Division, and Mr. J. P. Sale, Chief, SPL. This report was written by Messrs. A. N. Williamson and W. E. Grabau, MESL, and W. K. Dornbusch, SPL.

Directors of the WES during the conduct of this study and preparation of this report were COL A. G. Sutton, Jr., CE, COL J. R. Oswalt, Jr., CE, COL L. A. Brown, CE, BG F. D. Peixotto, CE, and COL G. H. Hilt, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

Contents

Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles	1.609344	kilometers
cubic feet/second	0.02831685	$meter^3$/second
acre-foot	1233.482	$meter^3$
square miles	2589.988	square kilometers

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Summary

Successful use of remote sensors requires considerably more than just taking some imagery or flying an area. Six essential processes that must be accomplished if use of a remote-sensing system is to result in useful information are defined herein as problem specification, ground control data acquisition, remote-sensor information acquisition, data manipulation, information extraction, and information presentation. Identification of these processes is the result of much experience at WES in remote-sensing techniques. Several fairly common and not so common sensor types are introduced, and some devices and information extraction and presentation techniques found to be useful in remote-sensing projects are described. An overview of the current state-of-the-art of remote sensing is presented and some of the current remote-sensing capabilities of WES are introduced.

REMOTE-SENSING PRACTICE AND POTENTIAL

Introduction

We have two objectives in presenting this report.

a. First, to convey to you a general overview of the state-of-the-art of remote sensing, as we perceive it. We think this may prove useful, because the art is presently rapidly advancing; new capabilities are being developed on an almost day-by-day basis, and it's hard to keep up with them even when one is, himself, involved in research in this area.

b. Second, to provide you with some insight into the current capabilities of the U. S. Army Engineer Waterways Experiment Station (WES) in the field of remote sensing and related areas. This capability has evolved as a product of research and development programs funded by a number of agencies. Prominent among these are Army Materiel Command, the Military Engineering and Topographic Directorate, and the Military Construction Directorate of the Corps of Engineers. We do not, by this, mean to imply that support from civil agencies has been lacking. For example, some very recent advances have stemmed from research programs funded by the National Aeronautics and Space Administration (NASA).

The term "remote sensing" is surely used in almost as many senses as there are people using the term. For the present purpose, the term describes any method of obtaining information about the environment that involves sensing and recording a form of energy reflected or emitted by the objects of interest. The energy may be electromagnetic (such as light, infrared, gamma radiation, or radar), acoustic (that is, sound waves), seismic (that is, harmonic motion in solid materials), or indeed any form of energy that is capable of carrying information from one place to another. There is no necessary implication of range; a photograph of an object from 2 m away is as valid an example of remote sensing as an image obtained by a satellite in an orbit 1000 km high.

It is impractical, in the following discussion, to attempt to include examples of all forms and types of remote-sensing systems. Instead, the discussion will be restricted largely to those which are normally operated from aircraft and/or earth-orbiting satellites, and which utilize electromagnetic radiation in the wavelength range from about 0.35 µm (i.e. ultraviolet) to several centimeters (i.e. radar).

Within this general category, there are two basic and widely used <u>types</u> of remote-sensing systems.

<u>a</u>. <u>Cameras</u> (fig. 1), which obtain an image of an entire scene at one time, and which record an image of the scene as a chemical change in a piece of film.

<u>b</u>. <u>Scanners</u> (fig. 2), which look at a lot of tiny areas in sequence and use the records obtained by that sequence to either build up an image like a mosaic or build up a record of a property of the scene along a "scan line."

For all practical purposes, all scanners are arranged so that the light (or other form of radiant energy) from a tiny "instantaneous field of view" falls on some kind of device that transforms the radiant energy into an electrical voltage. That voltage is proportional to the amount of radiant energy being received at any given time. Once the voltage is available, two fundamentally different kinds of things can be done with it, and this dichotomy leads to two important scanner subtypes:

<u>a</u>. <u>Analog systems</u> in which the analog voltage is used to drive a cathode ray tube (that is, a television tube) in such a way that a picture is formed on the face of the tube. This is more or less exactly analogous to the way a television set works. If one wants to record the image, the obvious thing to do is to take a picture of the image on the tube, in which case the final product is a hard-copy picture. The alternative is to record the analog voltage obtained from the sensing element, in which case the final product is an analog tape of the scene. The tape may then be used to drive a television viewer, thus, again, obtaining a picture of the scene.

<u>b</u>. <u>Digital systems</u>, on the other hand, take the analog voltage from the sensor element and run it through an analog-to-digital converter, and they then store the digital record on magnetic tape. The result is that each "instantaneous field of view" is represented on the tape by a digital record (that is, a number) that represents the total amount of radiant energy being received at that time.

So important are digital systems becoming that they have given rise to some new and widely useful terminology. Recall that the

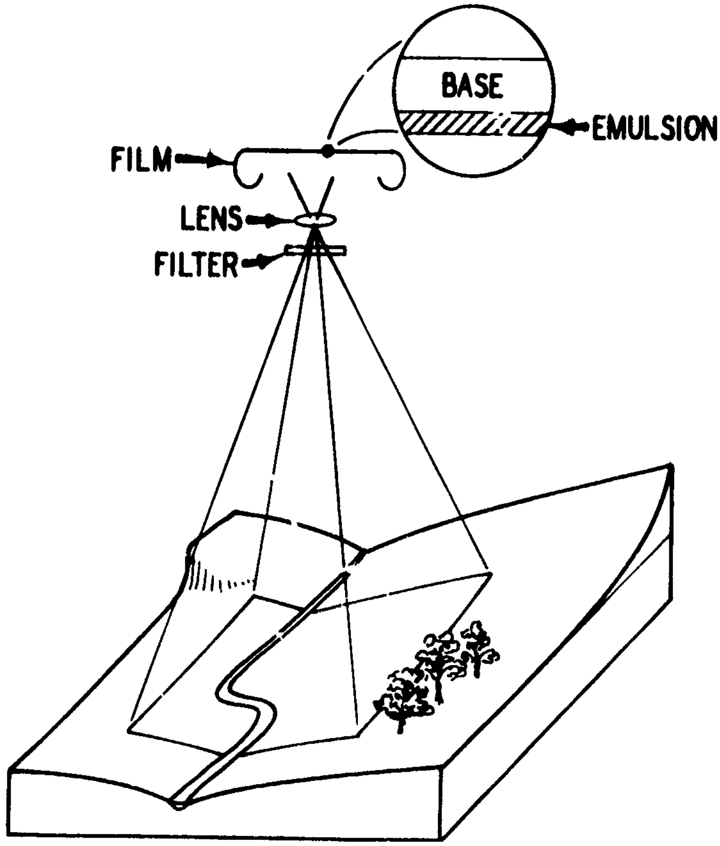

Fig. 1. Operation of camera

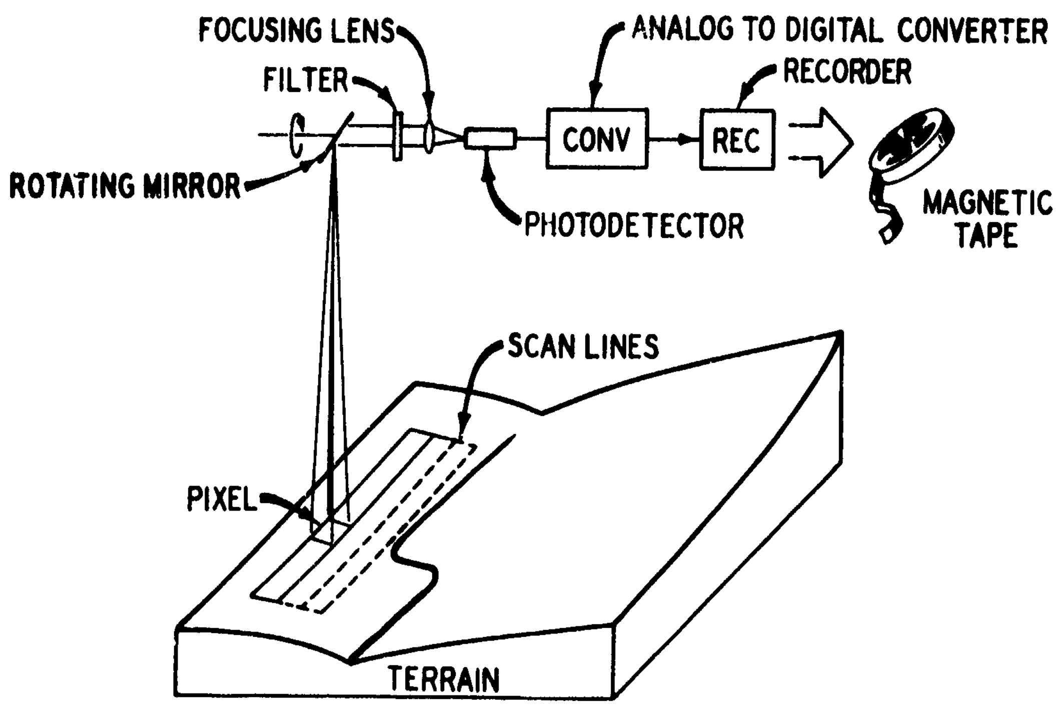

Fig. 2. Operation of scanner using digital recording

"instantaneous field of view" is a basic unit or element of a picture, in almost exactly the same sense that a tessera is a basic unit or element of a mosaic. However, instead of using the term "tessera" to describe this element (presumably because the word had too many classical allusions), people began using the term "picture element," and this was promptly shortened to "pixel." You may as well become accustomed to using it, because it will be around for a long time; it turns out that it describes a basic attribute of <u>all</u> picture-forming processes, including that employed by the human eye.

The technical definition is: A pixel is that area of view over which all received radiant energy is integrated into a single value. In the human eye the sensing element is a single retinal cell, and all visible light falling on that cell is integrated into a single value; that is, to an electrical analog of proportional value.

Finally, there are a number of remote sensing systems that cannot readily be fitted into any neat and simplistic classification system. The most common forms using electromagnetic waves are really range-finding devices; they emit a beam or impulse of energy, and by one device or another measure the time it takes for the pulse to make the round trip from aircraft to ground and back again. Since electromagnetic waves travel at pretty constant speed, that value is readily converted into a measure of distance. That value may then be recorded as either an analog or digital record on various media, but usually magnetic tape.

This scheme can exploit waves through physical media, like sound waves through air, and acoustic and seismic waves through water or soil or rock. One very common remote sensor that falls into this category is the sonic depth finder.

Another basic type, still highly experimental, is a device that measures gamma ray emissions from soils, rocks, and so on. It is really a particle counter (fig. 3); it sorts the particle counts according to energy level, adds up the number of gamma particles in a range of energy levels, and produces numbers which are sums of counts over some period of time. In effect, it is counting the number of radioactive atoms of certain types in the soil or rock. Since not all soils and rocks have

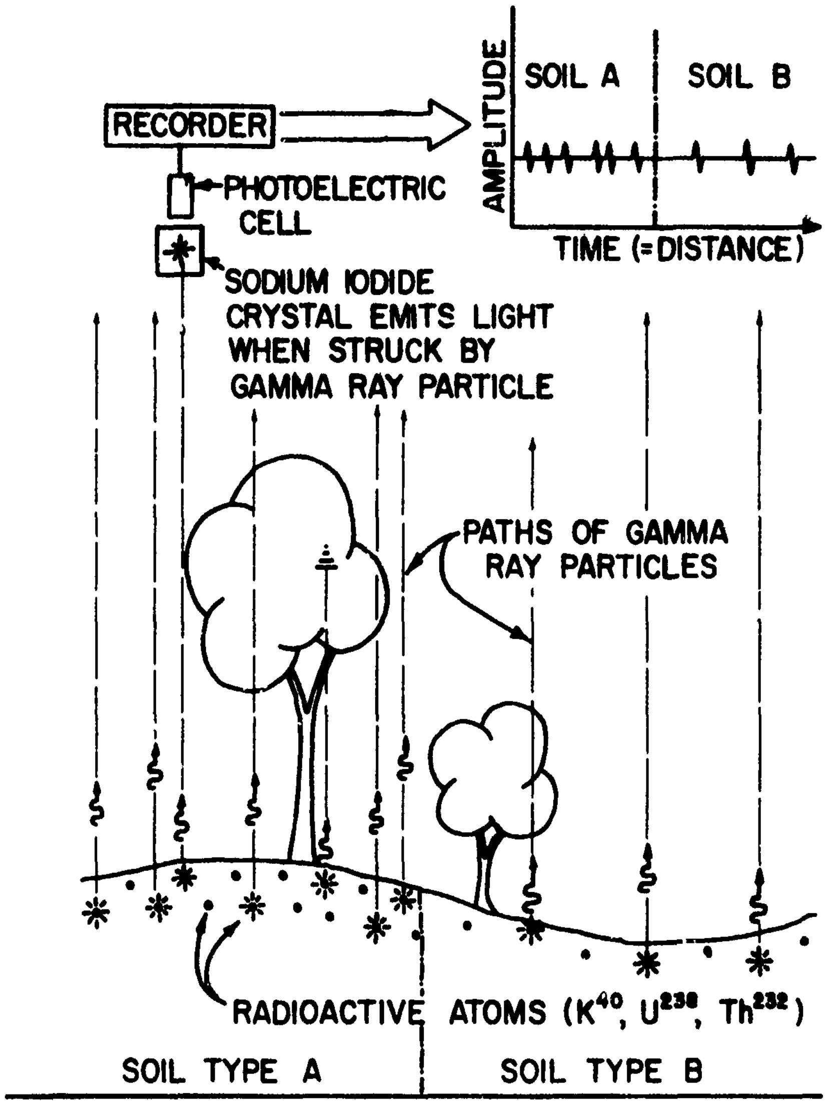

Fig. 3. Principle of operation: gamma ray sensor system

the same atomic compositions, these data can sometimes be used to discriminate among soil types that are difficult to separate by other remote-sensor systems.

Perhaps one additional characteristic of remote-sensing systems should be mentioned at this point. Some sensors are designed to operate with natural sources of radiation, and others are intended to utilize artificial sources. But the distinction is far, indeed, from being simple and straightforward, except in a few special cases. In general, those which almost exclusively use artificial sources are those which use millimeter and radar waves; in effect, these devices carry "searchlights" that illuminate the landscape, and the sensing element records the reflected energy. Many, but not all, sensors of the range-finding type use artificial energy sources. For example, the range finders that use visible or infrared frequencies use a laser to generate the necessary beam. However, another type, the gamma ray detector, employs gamma particles naturally emitted by the soil. Those sensor systems that operate in the wavelength range from ultraviolet through visible to near-infrared almost always use ambient light (that is, sunlight), but there is no rule that says that one cannot use a flare or a searchlight. Systems designed for military use commonly use such light sources. Systems using thermal infrared mostly use natural radiation, since they are essentially sensing the temperature of things.

So much for definitions and classifications. Each of the types and subtypes come in almost numberless forms, and many devices exist which are combinations of two or more types. There is little point in trying to cover them all; others will have been invented during the time taken to describe them. Out of this abundance of variations, there are two vitally important things to keep in mind concerning remote-sensor systems: the type of product that they produce (fig. 4) and the wavelengths of the electromagnetic energy that they employ.

The output products are important because all of the information obtained by the sensor system is stored in that product. Thus, the form of product very largely dictates the interpretive or analytical procedures that can be employed. While products are highly variable in detail, the following generalizations largely apply:

a. Cameras produce hard-copy pictures.

b. Analog scanners produce hard-copy pictures (or sometimes an analog magnetic tape).

c. Digital scanners produce a digital magnetic tape.

The second important thing to keep in mind, namely the wavelengths which are being employed (fig. 4), is important because each wavelength or group of wavelengths exhibits unique capabilities and constraints.

SPECTRAL BAND	WAVELENGTHS	REMOTE SENSOR TYPE: CAMERAS	SCANNERS: ANALOG	SCANNERS: DIGITAL	OTHERS
GAMMA RAYS	0.7 - 2.0 Mev				X
ULTRAVIOLET	0.004 - 0.38 μm	X	X	X	X
VISIBLE	0.38 - 0.75 μm	X	X	X	X
NEAR-INFRARED	0.75 - 1.35 μm	X	X	X	X
INTERMEDIATE INFRARED	1.35 - 5.5 μm		X	X	X
THERMAL INFRARED	5.5 - 14.0 μm		X	X	X
MILLIMETER WAVES	0.1 - 10.0 mm		X	X	X
CENTIMETER WAVES	10 - 1,000 mm		X	X	X
TYPE OF PRODUCT					
HARD COPY PICTURES		X	X		
ANALOG MAGNETIC TAPE			X		X
DIGITAL MAGNETIC TAPE				X	X

Fig. 4. Types of remote sensor systems using electromagnetic radiation

There are three major reasons for keeping wavelengths in mind:

a. Different materials absorb, reflect, or emit the various wavelengths in different proportions, and thus some wavelengths are more suitable for looking at certain things than other wavelengths. For example (fig. 5), the

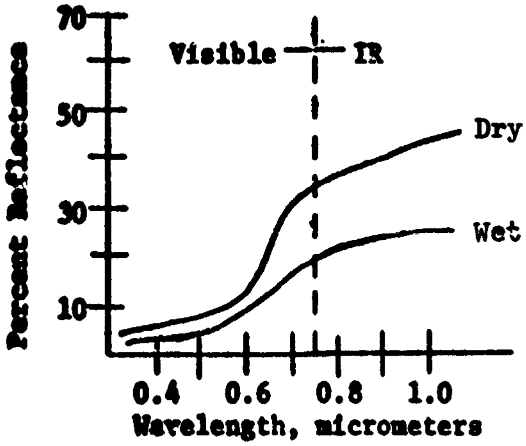

Fig. 5. Spectral reflectance curves for wet and dry sand, monument Valley, Utah

difference in reflectance between wet and dry sand at a wavelength of 0.5 μm is only about 4 percent, which means that the contrast between the two <u>at that wavelength</u> is very low. However, at a wavelength of 1.0 μm, the difference in reflectance is about 19 percent, which means that the available contrast is much stronger.

<u>b</u>. The atmosphere selectively absorbs or scatters certain wavelengths more than others, and thus it is hard to see through the atmosphere with certain wavelengths. For example (fig. 6), for all practical purposes no radiation

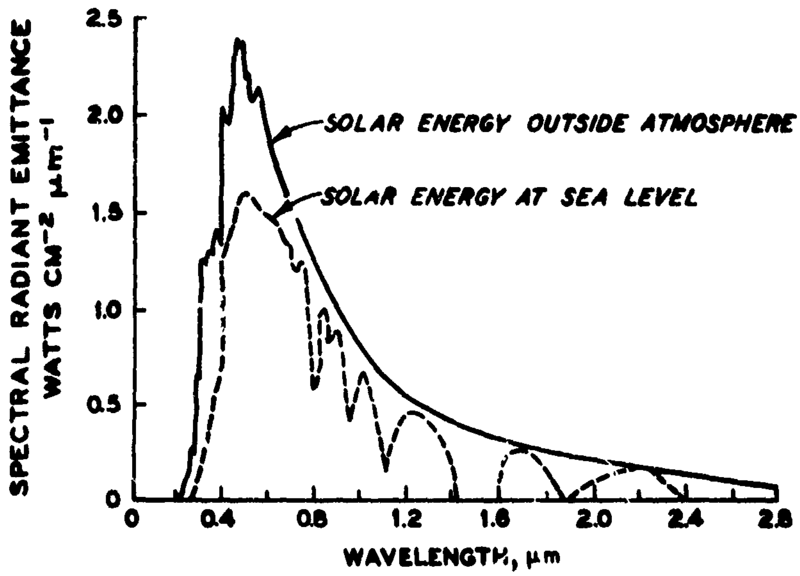

Fig. 6. Spectral distribution of solar energy, sun directly overhead

having wavelengths between about 1.45 μm and 1.6 μm will penetrate the atmosphere, so there is little point in trying to use radiation in that band.

<u>c</u>. The different wavelengths require widely different receivers or sensing systems. Thus, a camera operating in the visible wavelengths can be small and compact, while a scanner operating in the far infrared requires elaborate refrigeration equipment in addition to the basic electronics of the sensor system itself.

Since at present our interest is chiefly in those cameras and scanners using electromagnetic waves, let us consider only those sensors using such energy forms:

<u>a</u>. <u>Camera</u> systems operate with wavelengths ranging from about

0.3 μm (i.e. in the ultraviolet) to about 1.5 μm, which is in the near-infrared.

b. Scanner systems (either analog or digital) are available that operate over the very broad range from ultraviolet to radar. However, no one instrument can sense more than a comparatively narrow band, so that in practice, a separate instrument system is required for each of the wavelength categories listed in fig. 4.

c. The oddball systems (identified as "others" in fig. 4) may exploit wavelengths from gamma rays to radar. However, just as for the more conventional systems, for all practical purposes, a separate instrument is needed for each wavelength category. For example, laser profilometers may use wavelengths from ultraviolet to infrared, but in any one instrument the wavelength is restricted to a very narrow band.

Procedures and Capabilities

The successful use of remote-sensing systems almost invariably implies that six essentially sequential processes have been carried out (fig. 7).

- **PROBLEM SPECIFICATION**
- **GROUND CONTROL**
- **DATA ACQUISITION (WITH A REMOTE SENSING SYSTEM)**
- **DATA MANIPULATION**
- **INFORMATION EXTRACTION**
- **INFORMATION PRESENTATION**

Fig. 7. Processes involved in successful remote sensing

a. Problem specification (what problem are we trying to solve; what kinds of information are needed to solve it; and can a remote-sensing system obtain any or all of the needed information?)

b. Acquisition of ground-control data (determination of how the things of interest are related on the ground in selected locations, to serve as a basis for interpreting those relations over the entire region of interest).

c. Information acquisition with a remote-sensing system (the actual process of sensing and recording the region of interest at the time of interest).

d. Data manipulation (putting the information obtained by the remote-sensing system into a form suitable for analysis and/or interpretation).

e. Information extraction (actually performing the analysis and/or interpretation to obtain the needed data from the product of the remote-sensing system).

f. Information presentation (putting the extracted data into a form in which it can be used to assist in solving the problem at hand).

Before proceeding any further, a word of caution is in order. Remote sensing is one of several possible tools for obtaining information. It is not, by itself, a way of solving engineering or environmental planning problems, any more than a slide rule or a calculating machine is a way of solving them. In the latter case, someone has to know which buttons to push. In the case of remote sensing, someone has to know how to extract needed information from the sensor product, whether it be a picture, a digital magnetic tape, or whatever. Remote sensing is not a panacea for all information-gathering requirements; there are some kinds of information that simply cannot be obtained by remote-sensing techniques. On the other hand, there are kinds of information which for all practical purposes can only be obtained by remote sensing. All possible intermediate positions exist.

Having said this, let us proceed to a step-by-step examination of current capabilities in each of the six processes previously identified.

Problem specification

The use of remote sensing to acquire data that are required to solve problems is almost invariably a systems analysis problem; the entire problem must be looked at as a whole. In general, this usually means that some kind of conceptual scheme for solving the problem must be visualized. Such schemes (or, in the jargon, models) normally require a careful statement of the objective and an equally careful identification of each step in the information flow from present state-of-the-art to final solution. They need not include the equations, of course, but they must include a reasonable notion of how to derive those equations.

We have found that one of the best methods of generating a conceptual scheme or model of a problem-solving exercise is to flow-diagram it. For example, let it be assumed that we need to determine the distribution of water hyacinth mats in streams and lakes over some large area (fig. 8). This is a real, live problem in some parts of the United States; such information is badly needed to plan aquatic weed-control programs.

The arrows in fig. 8 mean: take the information in this block and perform the operation indicated at the point of the arrow. For example, if we need the exact shape and size of the water surface in a lake at a given time, one of the best ways available is to first describe the geometry of the lake basin very precisely, after which the shape and size can be readily calculated from a specification of water surface elevation.

A careful examination of even this very general flow diagram will quickly reveal that there are six areas where there are massive data requirements. Looking carefully at those six sets of data requirements, it is reasonably apparent that only three of them are readily amenable to acquisition by remote-sensing techniques, namely those indicated by triangles in the upper right corners of the boxes. Methods for obtaining such data will be discussed later, but in the meantime, it is clear that this almost elementary analysis has narrowed the remote-sensing part of the problem down to reasonably manageable proportions.

The "problem model" described above is quite simple and straightforward. Unfortunately not all problems are so easy to visualize. The example illustrated by fig. 9 is a far more complex model, in which each block in the figure is a separate problem at least as complex as the problem diagrammed in fig. 8. In this exercise, the objective was to determine the long-term systems costs of a number of alternate combinations of reservoirs on the Cheat River drainage basin in West Virginia.

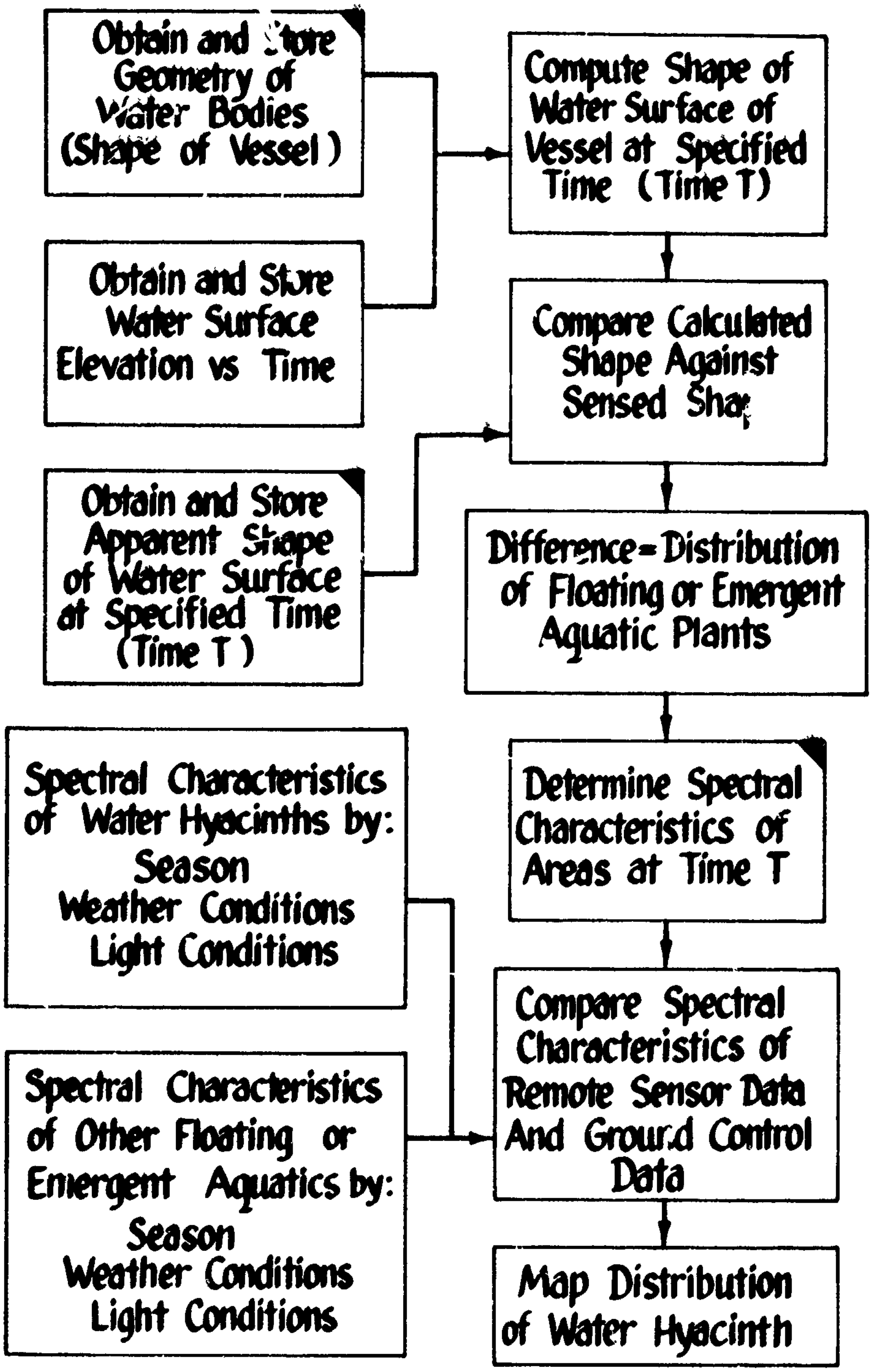

Fig. 8. Location of water hyacinth mats

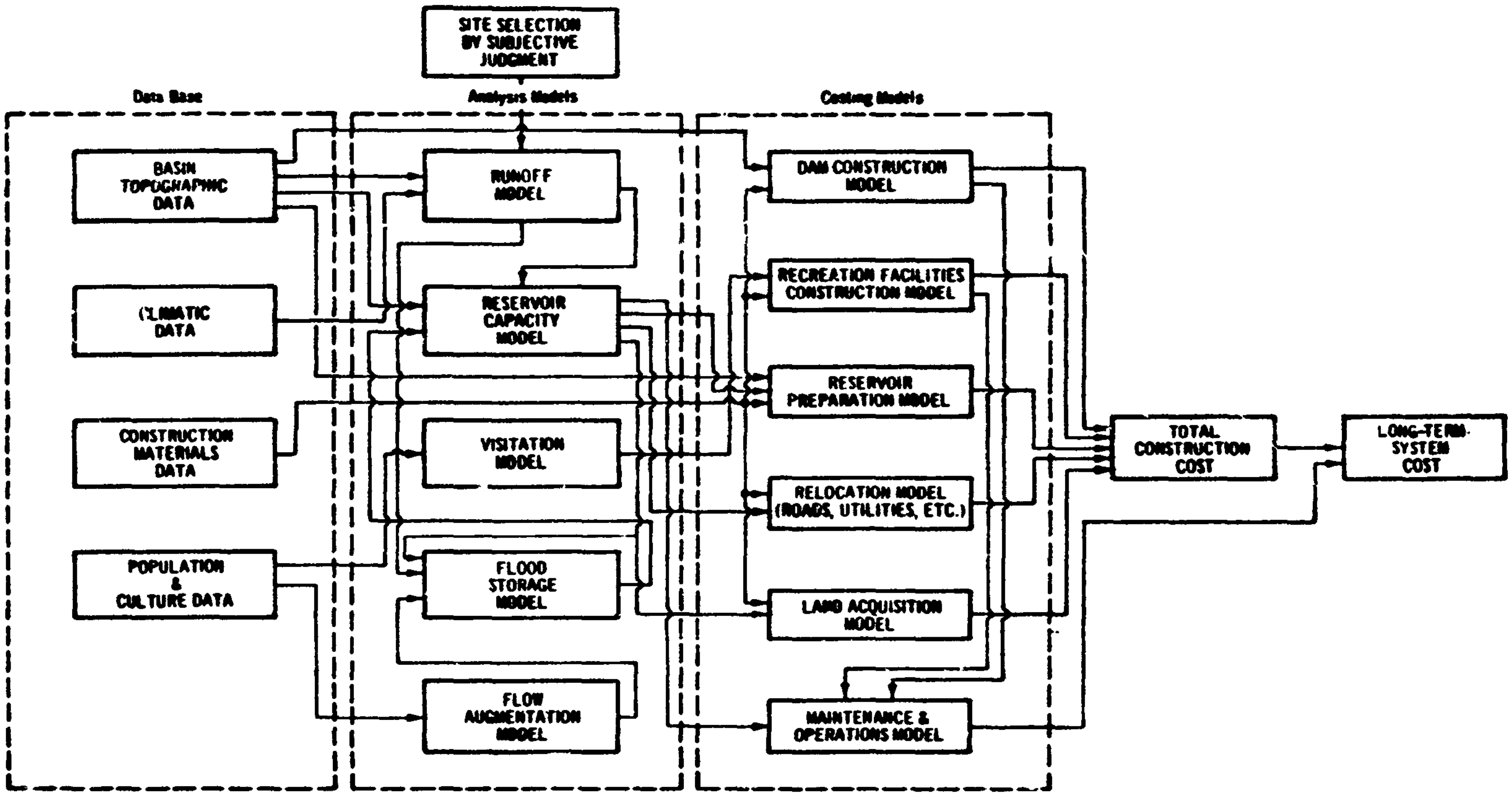

Fig. 9. Costing model of regional runoff control

The basic constraints were that each array of reservoirs had to store a stated minimum amount of floodwater, and had to store enough water to maintain a stated minimum flow in the Monongahela River below the mouth of the Cheat River. The period of analysis was from 1975 to 2020.

Considering the blocks indicated as the data base, it is clear that remote-sensing systems could be used to provide information relevant to three of the blocks: (1) basin topographic data; (2) construction materials data, especially with respect to the location of rock and soil suitable for use in earth and/or rock-fill dams; and (3) cultural data, specifically the locations and categorizations of roads, power lines, and the like. Thus, even at the very generalized level represented by fig. 9, a conceptual model is often of great help, since it identifies the terrain factors relevant to the problem in hand and suitable for acquisition by remote-sensing systems.

A conceptual model, as described above, is one of the important things one gets by applying systems analysis to problems involving complex interactions among natural phenomena. Unfortunately, systems analysis is more art than science. Since it is notoriously difficult to transfer art from one person to another, perhaps the best that can be done in the present instance is to invoke the aid of the artist. We at WES have been practitioners of the art of systems analysis for quite some time, and of course our services are available.

Ground control

It is almost a truism among those experienced in remote sensing that the information obtained by interpretation or analysis of remote-sensor system products is only as good as the ground control. It is a truism because the cold facts of the matter are that a lot of different things can look alike on a photograph. For example, every photo interpreter knows that dry soils look lighter on panchromatic photos than wet soils, and that in general the wetter the soil, the darker the appearance. But some soils are just naturally dark colored, and there is no way, from the photo alone, to discriminate between a patch of dark-colored dry soil and a patch of light-colored wet soil. Given adequate ground control, however, such discriminations are usually fairly easy, because it normally turns out that the two soils have different relationships to surrounding features. Once that is known, a skilled interpreter is home free. But lacking that knowledge, he may well be helpless. And such knowledge, by and large, can only be obtained by examining some examples of the occurrence on the ground; that is, by ground control.

One of the more frustrating aspects of the use of remote-sensing systems is the fact that the need for ground control is widely recognized--but only by those engineers and scientists who use remote-sensing systems to help them solve real-world problems. Those who do not have such a background in experience tend to either overlook the need completely or at best to underestimate the importance, and the cost, of obtaining it. In our experience, the cost of obtaining adequate ground control often exceeds all other project costs combined. This is simply one of those unfortunate facts of life.

The problems posed by acquiring the necessary ground control have led WES to pay very particular attention to all aspects of the process. For example, the interpretation of air photos commonly depends on knowledge of weather conditions before and during the data-acquisition phase. Clearly, if it rained the day before, the interpreter ought to be forewarned that all of the soils are going to look darker than would otherwise be the case. However, it very often is difficult, or indeed sometimes impossible, to obtain weather information from conventional sources in exactly the time and place where it is needed. For this purpose, we have designed and built a self-contained micrometeorological station (fig. 10). It operates on self-contained batteries, will handle up to 20 instruments simultaneously (or 36 instruments, if needed), and stores up to 15 days of instrument readings on a little reel of magnetic tape. After computer processing, the data may be output as a table (fig. 11) or as a graphic (fig. 12). A variation of this system can be used to monitor certain water-quality parameters, soil moisture and/or temperature, solar radiation, or indeed many other kinds of things.

Some kinds of information can best be extracted from remote-sensing system products by spectral analysis (which will be described

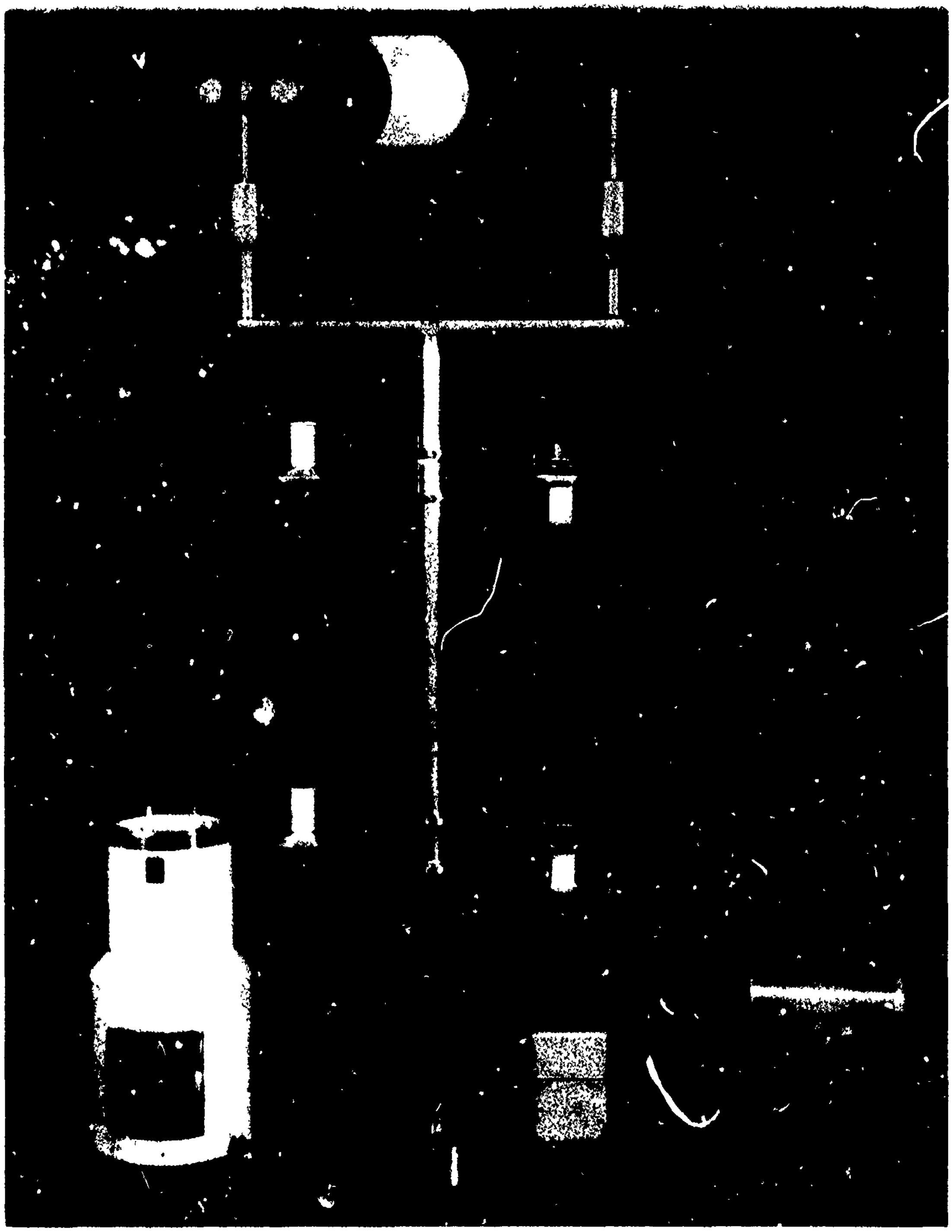

Fig. 10. Micrometeorological station

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TABLE A

USAEWES AUTOMATIC WEATHER STATION RECORDINGS

PUERTO RICO-SITE BEGINNING DATE-17 JUNE 1971 ELEVATION ABOVE SEA LEVEL-95.5 METERS

IDENT. NO.	TIME, HRS/MIN	TEMPERATURE, DEGREE CENTIGRADE				ABSOLUTE ATMOSPHERIC PRESSURE, INCHES OF MERCURY	SOLAR METER, CAL PER SQ CM PER MIN					
		10	11	12	13	14	15	16	17	18	19	
1	0.00	22.67	29.04	30.27	30.09	30.07	0.43	0.23	1.16	0.22	0.21	
1	0.15	24.55	29.30	30.45	30.00	30.04	0.50	0.23	1.15	0.22	0.20	
1	0.30	24.47	29.13	31.22	31.11	30.02	0.56	0.23	1.14	0.22	0.43	
1	0.45	24.84	28.79	28.20	28.11	30.03	0.52	0.18	0.72	0.18	0.20	
1	1.00	25.50	28.03	28.11	27.95	30.04	0.43	0.14	0.42	0.14	0.00	ERROR IN DATA
1	1.15	26.35	27.70	30.36	30.82	30.05	0.65	0.21	1.03	0.20	0.22	
1	1.30	25.96	27.70	29.04	28.62	30.05	0.49	0.16	0.53	0.16	0.19	
1	1.45	25.28	27.62	28.36	28.62	30.06	0.44	0.15	0.45	0.15	0.18	
1	2.00	25.81	27.38	30.54	30.00	30.06	0.49	0.18	0.77	0.18	0.00	ERROR IN DATA
1	2.15	24.62	27.13	27.46	27.30	30.06	0.34	0.13	0.34	0.13	0.16	
1	2.30	24.33	26.97	26.97	26.97	30.07	0.30	0.13	0.30	0.13	0.15	
1	2.45	24.47	26.74	28.96	29.04	30.07	0.35	0.16	0.52	0.16	0.16	
1	3.00	23.75	26.58	28.45	28.62	30.07	0.33	0.15	0.46	0.15	0.15	
1	3.15	23.69	26.35	26.27	26.19	30.08	0.23	0.12	0.23	0.12	0.13	
1	3.30	23.49	26.35	26.35	26.42	30.08	0.23	0.12	0.24	0.12	0.13	
1	3.45	23.35	26.04	26.35	26.35	30.09	0.19	0.12	0.21	0.12	0.12	
1	4.00	22.47	25.88	25.43	25.35	30.09	0.15	0.11	0.15	0.11	0.11	
1	4.15	22.67	25.73	24.84	24.84	30.10	0.13	0.11	0.13	0.11	0.11	
1	4.30	22.47	25.66	24.91	24.91	30.12	0.12	0.11	0.12	0.11	0.11	
1	4.45	22.47	25.50	24.84	24.69	30.12	0.11	0.11	0.11	0.11	0.11	
1	5.00	22.54	25.50	24.84	24.76	30.12	0.11	0.11	0.11	0.11	0.11	
1	5.15	22.34	25.35	24.40	24.40	30.13	0.11	0.11	0.11	0.11	0.11	
1	5.30	22.47	25.28	24.69	24.62	30.14	0.11	0.11	0.11	0.11	0.11	
1	5.45	22.54	25.13	24.33	24.40	30.14	0.11	0.11	0.11	0.11	0.11	
1	6.00	22.47	25.13	24.55	24.55	30.14	0.11	0.11	0.11	0.11	0.11	
1	6.15	22.40	25.13	23.69	23.62	30.15	0.11	0.11	0.11	0.11	0.11	ERROR IN DATA
1	6.30	22.40	25.13	23.69	23.55	30.15	0.11	0.11	0.11	0.11	0.11	
1	6.45	22.40	24.98	23.55	23.49	30.17	0.11	0.11	0.11	0.11	0.11	
1	7.00	22.40	24.98	23.62	23.55	30.16	0.11	0.11	0.11	0.11	0.11	
1	7.15	22.27	24.76	23.28	23.28	30.17	0.11	0.11	0.11	0.11	0.11	
1	7.30	22.34	24.62	23.35	23.35	30.18	0.11	0.11	0.11	0.11	0.11	
1	7.45	22.34	24.47	22.94	22.87	30.18	0.11	0.11	0.11	0.11	0.11	
1	8.00	22.34	24.33	22.60	22.60	30.18	0.11	0.11	0.11	0.11	0.11	
1	8.15	22.34	24.33	22.47	22.47	30.19	0.11	0.11	0.11	0.11	0.11	
1	8.30	22.34	24.19	22.54	22.54	30.19	0.11	0.11	0.11	0.11	0.11	
1	8.45	22.27	24.19	22.34	22.27	30.19	0.11	0.11	0.11	0.11	0.11	
1	9.00	22.34	24.05	22.01	22.21	30.19	0.11	0.11	0.11	0.11	0.11	
1	9.15	22.27	23.90	22.21	22.34	30.19	0.11	0.11	0.11	0.11	0.11	
1	9.30	22.27	23.83	21.95	21.88	30.20	0.11	0.11	0.11	0.17	0.11	
1	9.45	22.21	23.76	22.21	22.21	30.20	0.11	0.11	0.11	0.11	0.11	
1	10.00	22.21	23.62	22.01	22.08	30.20	0.11	0.11	0.11	0.11	0.11	
1	10.15	22.27	23.62	21.82	21.69	30.20	0.11	0.11	0.11	0.11	0.11	

Fig. 11. Sample listing from micromet package

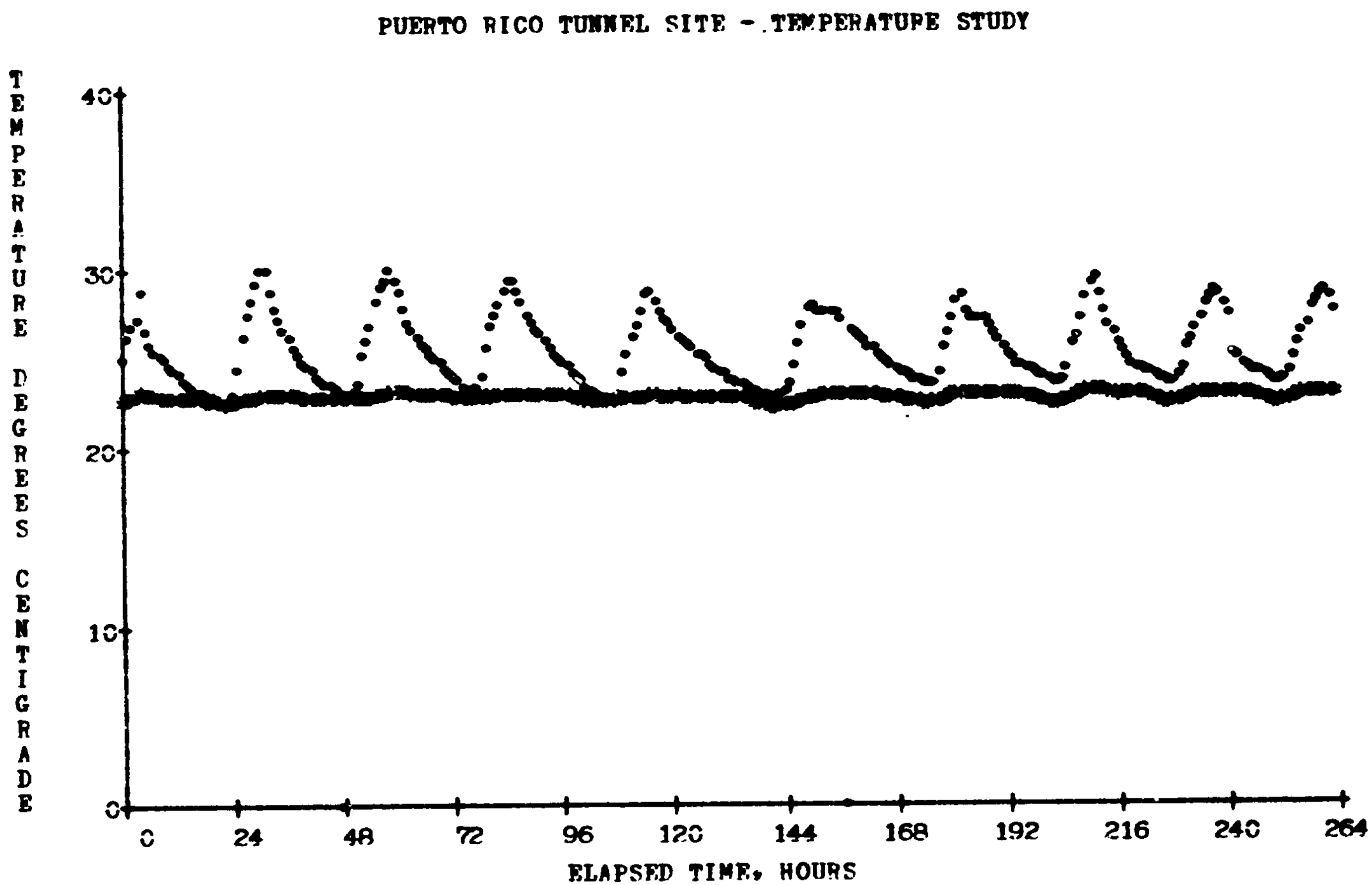


Fig. 12. Example of computer-generated plot

in greater detail later). If this procedure is to be used successfully, one absolutely necessary component of the ground control is the reflectance properties of the materials of interest, whether they be suspended sediments in water, pollutants, particular species of plants, or whatever. For this, one needs a device that measures the amount of energy in several wavelength bands (fig. 13). We have equipped ourselves with

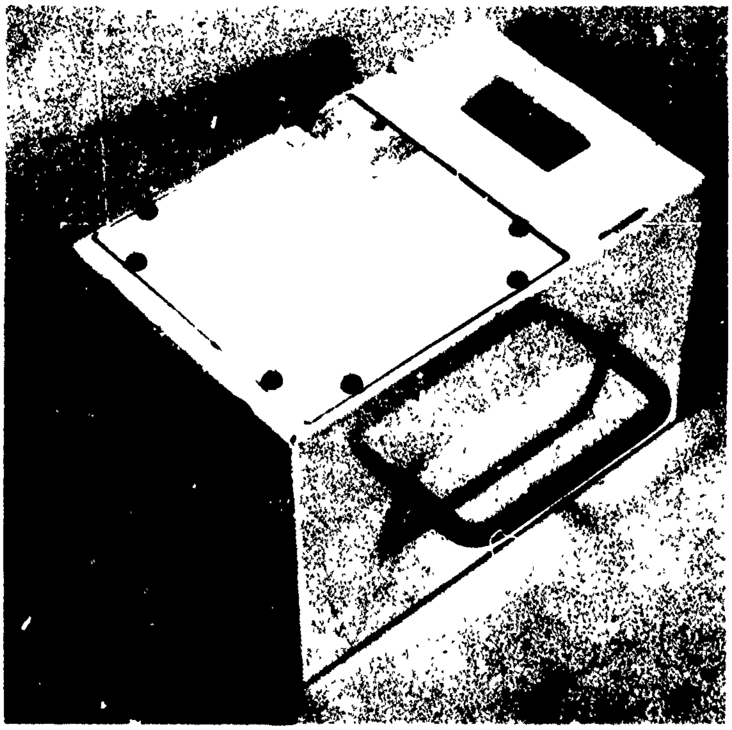


Fig. . Radiometer for ERTS-1 studies

such instruments. The one in the illustration measures the four spectral bands corresponding to those viewed by the scanner aboard NASA's Earth Resources Technology Satellite (ERTS-1). We are also equipped with a wide variety of soil-testing equipment, water-quality devices, and standard (and some not-so-standard) surveying equipments.

While equipment and instrumentation are important, they are by no means the only important consideration in obtaining good ground control. The second, and in some ways even more important, part of the equation is technique. That is, the methods that are used, both in the field and in the office, are as important as the instruments. Office procedures are often of primary concern because it usually turns out that organizing and presenting ground-control data for the use of the photo interpreter or data analyzer are major items of time and cost. This is especially true if large volumes of data are involved, as is very commonly the case.

When one looks at a photograph, much of the information it contains is presented to the observer as <u>geometric</u> information; that is, the interpreter sees the <u>shapes</u> of things. Thus, it commonly occurs that a requirement of the ground control is that it include remarkably precise information on the shapes and sizes of things on the ground. For example, one of the things we have had to develop is a remarkably detailed method of describing the three-dimensional geometries of trees and bushes. It starts out with a special setup involving a theodolite with a special reticle and a laser (fig. 14) and ends up with a file in a computer that is able to draw a picture of the tree (fig. 15) or,

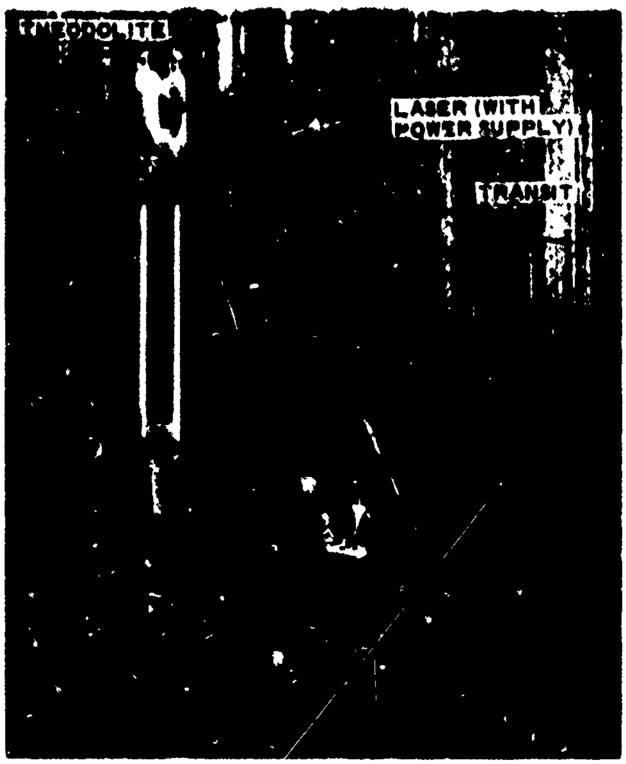


Fig. 14. Instrumentation used in tree dimensioning system

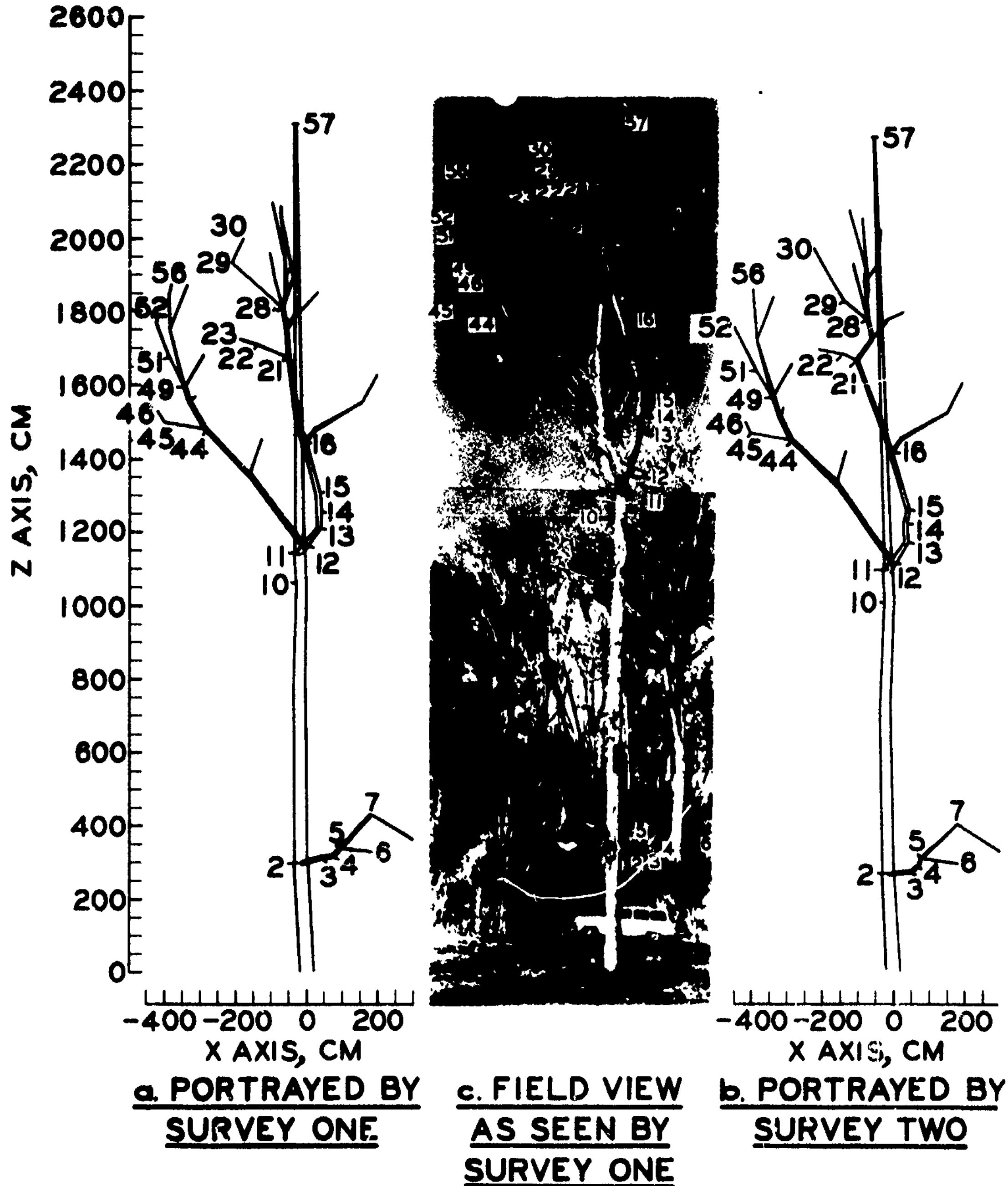
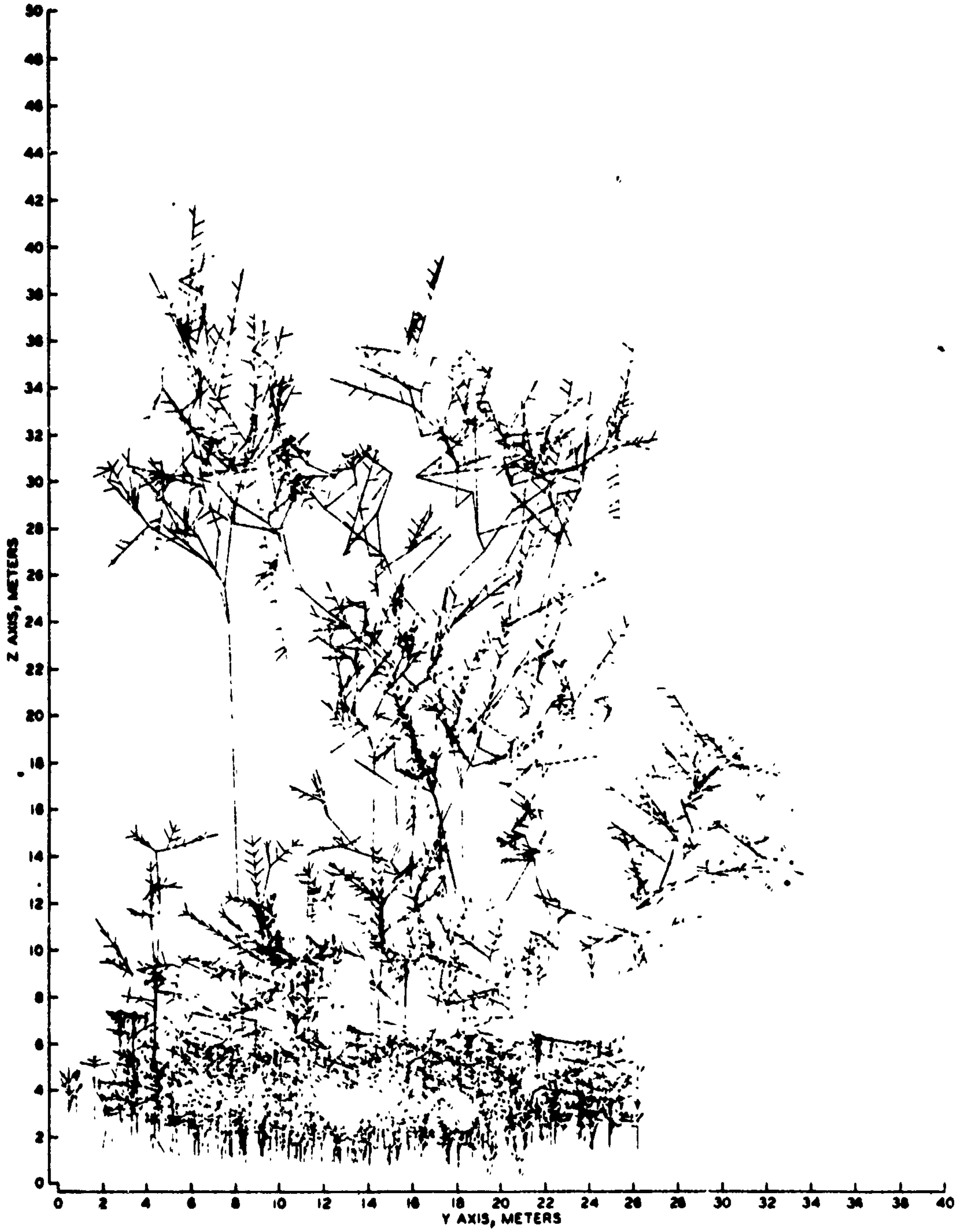


Fig. 15. Comparison of two XZ views, sycamore tree, Vicksburg, Miss.

indeed, of a forest (fig. 16) from any point of view. The trees in this figure are as they would look in the winter; we can put leaves on them, too, if you'd like.



NOTE: SITE CONTAINS BRANCHES ≥ 2MM IN DIAMETER.

Fig. 16. Profile of standard tropical forest site P3-10, Panama Canal Zone

Normally, of course, such exquisite detail is not required. But the point we wish to make is that really up-to-date data-processing techniques are capable of handling enormous amounts of data in practical lengths of time at practical costs. There is no longer any reason to fear problems that involve large data files, because machines can be instructed to do nearly all of the work.

It should be noted that, while computers with large core memory capacities are nice to have, they are usually not essential. Clever programming can make a small computer do rather remarkable things, as we will discuss in more detail a bit later.

The fundamental reason why automatic data processing is not more widely used is that there is a considerable measure of skill involved in setting up a data storage and retrieval system in such a way as to make it easily usable by "noncomputerniks." We have considerable experience in such matters. For example, one major current problem involves questions regarding threatened species. If there is a plan to make any major modification of the environment, these questions (fig. 17) (and many others) are immediately asked. What one might like to

TYPICAL QUESTIONS:

- **ARE THERE ANY THREATENED SPECIES IN MY AREA THAT I NEED BE CONCERNED ABOUT?**
- **WHAT IS THE LEGAL STATUS OF THREATENED SPECIES IN MY AREA?**
- **WHAT ARE THE HABITAT REQUIREMENTS OF THE SPECIES?**
- **WHAT LITERATURE SOURCES CAN I CONSULT FOR MORE INFORMATION?**
- **WHAT IS THE TOTAL RANGE OF THE SPECIES?**
- **WHO ARE THE EXPERTS ON THE SPECIES?**

Fig. 17. Catalog of threatened species

have is a quick and easy way to answer them. In response, we designed a catalog of threatened species in a format suitable for computer manipulation and provided access to that catalog by means of a conversational mode computer program. If you have access to a teletype terminal equipped with an acoustic coupler, you can talk to our computer in Vicksburg and get answers to these questions. This (fig. 18) is an

```
USER ID F747          FILE - CARD1A       PAGE 0021



STATE: ARIZONA
CLASS: MAMMAL
SPECIES: SPOTTED BAT (EUDERMA MACULATUM) (BSFW 1973)
STATUS: RECOMMENDED (INCLUDED IN "REDBOOK", BUT NOT ON
     FEDERAL REGISTER (BSFW 1973)); INFORMATION NOT AVAIL-
     ABLE FOR STATE STATUS.
DESCRIPTION: MEDIUM SIZE WITH SPECTACULAR APPEARANCE; BACK
     IS BLACK WITH THREE WHITE SPOTS; VENTRAL HAIR BLACK AT
     BASE BUT WHITE-TIPPED; LARGE PINK EARS, SOME INDIVI-
     DUALS HAVE WHITE AT BASE OF EARS, AND A BLACK BAND ON
     UNDERSURFACE OF NECK (BSFW 1973).
RANGE: ONE OR TWO RECORDS (MORE FROM TEXAS AND NEW MEXICO)
     FROM EACH OF THE SOUTHWESTERN STATES AND THE MEXICAN
     STATE OF DURANGO. IT HAS BEEN FOUND AS FAR NORTH AS
     YELLOWSTONE COUNTY, MONTANA, AND CANYON COUNTY, IDAHO,
     AND AS FAR EAST AS BREWSTER CO, TEXAS (BSFW 1973).
HABITAT: "A BAT OF THE HIGH CLIFFS AND CANYONS (SEDIMENTARY
     ORIGIN? ) LIVING IN THE CRACKS AND CREVICES DURING THE
     DAY. APPARENTLY HIGHLY SELECTIVE IN ITS ROOSTS, YET
     RANGES FROM PONDEROSA PINE BELT TO LOWER SONORAN LIFE
     ZONE," (BSFW 1973). NO INFORMATION AVAILABLE ON FORAG-
     ING HABITAT PREFERENCES (EEA).
```

Fig. 18. Typical teletype printout resulting from conversation with computer

example of the teletype printout that developed as a man began his search of the files.

If the problem is to determine the impact of new construction on an ecosystem, one thing that must be done is to determine whether the project will disturb the habitats of any threatened species. One uses the file to first identify the local species, if any. The investigator does this by calling the range and distribution maps for the relevant species out of the catalog (fig. 19) and checking to see if their ranges

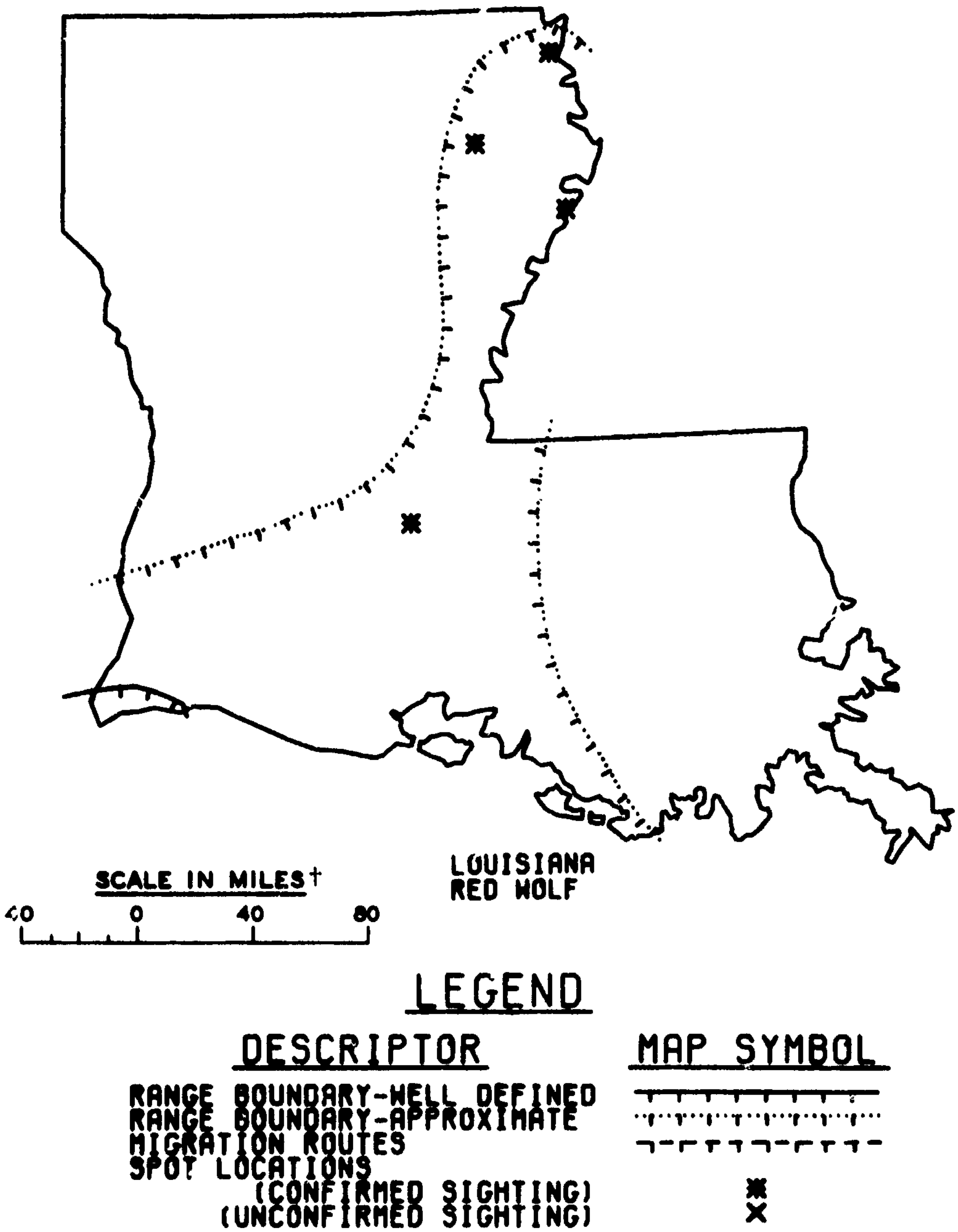


Fig. 19. Typical range and distribution map

† A table of factors for converting British units of measurement to metric units is presented on page ix.

77253

overlap the region of interest. If they do, one then looks in the file to determine their habitat requirements. Then one turns to remote sensing, perhaps to map the distributions of those habitats in the region of interest.

Information acquisition with remote-sensing systems

As was indicated earlier in this discussion, remote-sensing systems come in many different forms. To our regret, we have almost no internal capability to acquire information with remote-sensing systems. When we need remote sensor products, we have to buy them from commercial firms, or make arrangements with some other Government agency, such as NASA or Air Force, to obtain them for us.

However, this does not imply that it is not necessary to understand the intricacies of remote-sensor systems and their products. To the contrary, it is absolutely essential that one understands all aspects of the process if one is to use remote sensing effectively. Accordingly, a brief discussion of a few of the more important systems and their products is in order.

The first type, and by far the most commonly used, is a standard camera using a simple "haze filter" in front of the lens and panchromatic (i.e. black-and-white) film for image recording (fig. 20). Almost everybody is familiar with this product. The critical point is that it accepts light in a broad wavelength band (from about 0.4 to 0.8 µm) and presents the information in shades of grey. It has some advantages: it's cheap, widely available, easy to develop, and capable of recording a great deal of detail. If the problem involves metrics (that is, measurement of the dimensions of objects), this is the kind of film normally used. Its primary disadvantage is that it loses nearly all information carried by color.

Of course, standard color film can be used to retain spectral information in the visible part of the spectrum. This (fig. 21) is a picture of a part of a chenier (beach ridge) in Louisiana, taken with standard Ektachrome color film. The pictures tend to be aesthetically pleasing, but the spectral information is pretty qualitative, mostly

Fig. 20. Photograph taken with panchromatic (black and white) film

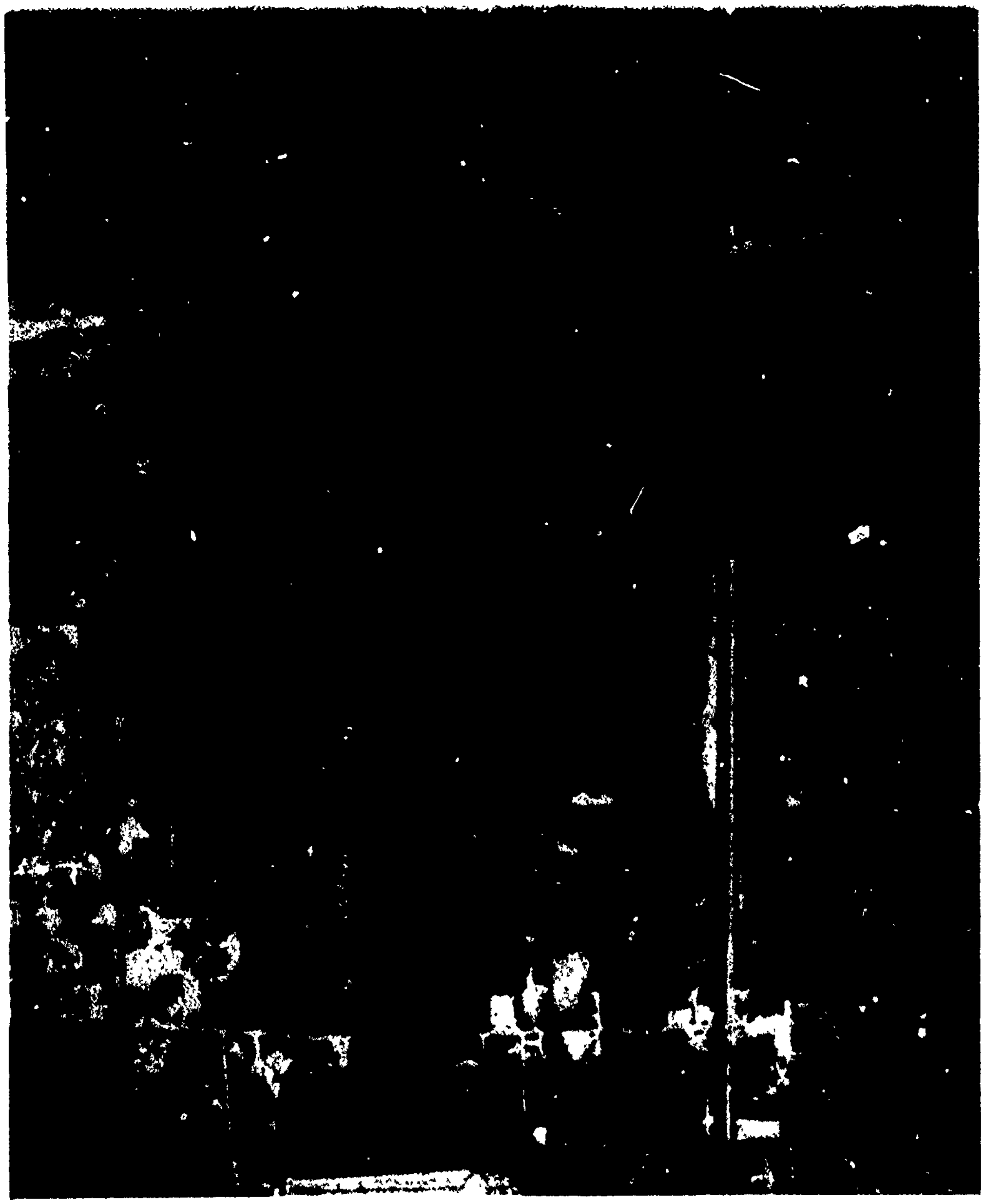


Fig. 21. Photograph taken on conventional color film.
(Original photo in color)

because it is extremely difficult to adequately control the chemistry in the development processes.

Cameras can also be used to extend the visual range into the infrared. One common procedure is to use what is usually called "false color infrared" film. This is a film which accepts "light" in the near-infrared (i.e. out to about 1.1 µm), as well as in a portion of the visible region of the spectrum. The pictures look a little odd, because things that you "know" are green, like vegetation, turn out red in the film. For example, here (fig. 22) is the same area as the previous picture, but imaged in false-color infrared. The thing to note is that details of the vegetation show a good deal more clearly than in pictures

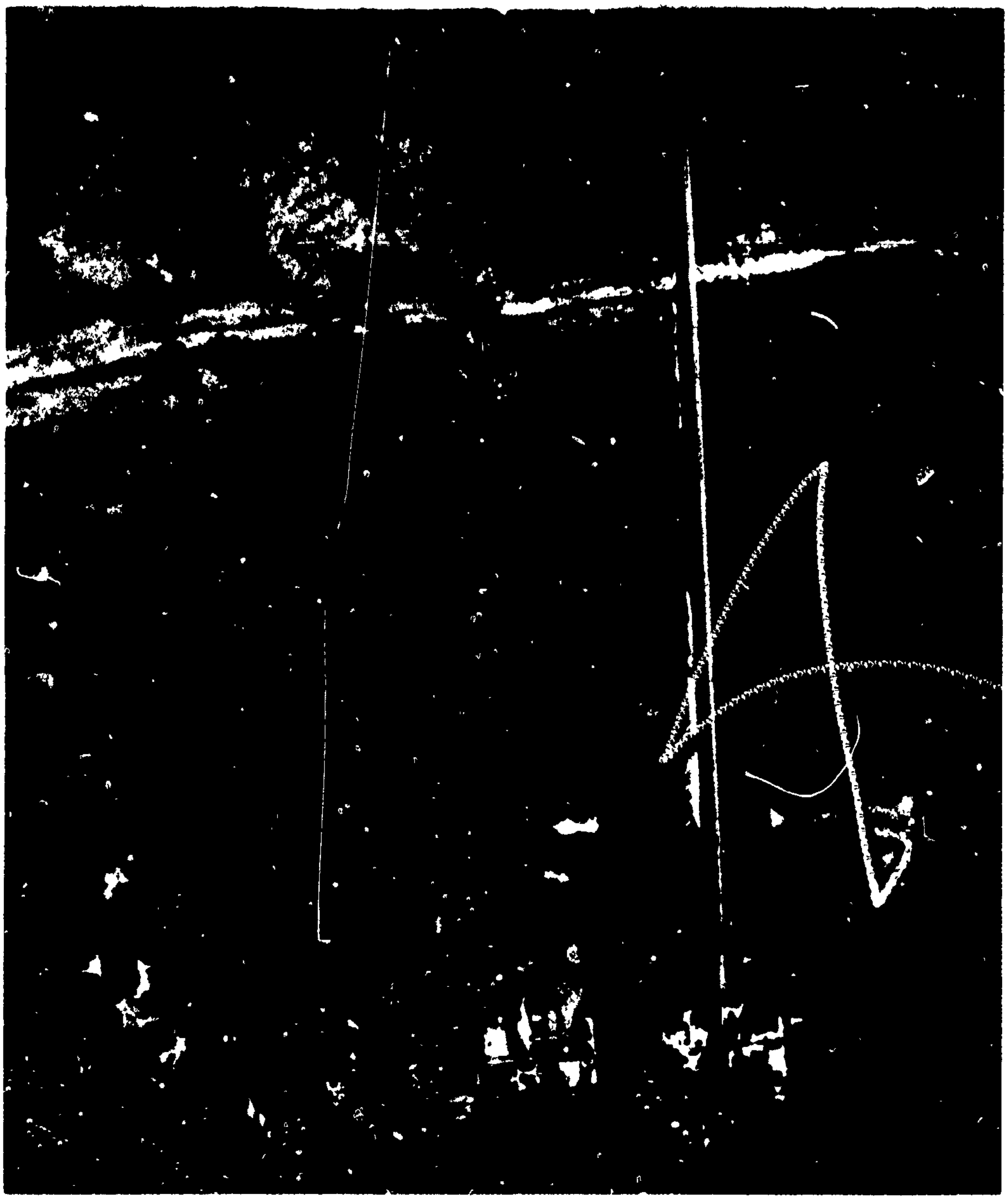


Fig. 22. Photograph taken on false-color infrared film.
(Original photo in color)

taken with standard color film. There is at least one other fringe benefit; water shows in marked contrast to vegetation, as illustrated in this picture (fig. 23) of a water hyacinth mat in a Florida river. This film is widely used for crop inventories, because healthy plants look bright red, and sick plants look pale red, and dead plants look white, even though they are all the same color to the unaided eye. Note that this picture is not taken at the vertical; oblique views such as this are often of great value, especially for reconnaissance purposes.

There are many variations of systems designed to retain information carried by color (or, in the jargon, to retain spectral information). For example, one standard gambit is to mount several cameras side by side, and select film and filter combinations for each so that each one accepts light in a specific and relatively narrow wavelength band (or, again to use jargon, a spectral band). One camera designed specifically to photograph a scene simultaneously in four spectral bands is the I^2S camera which produces four images (fig. 24), each in a different spectral band. In effect, the visible spectrum is split into four equal parts. If what you are looking for can be identified because of a specific spectral composition, then this kind of system may be what you need. However, it takes a very skilled interpreter to use this kind of information effectively, and such people are not found under every bush. Obtaining multispectral images is a good deal more expensive than obtaining panchromatic images, so in general our advice is to obtain such imagery only in those instances where your interpretive capability is equal to the challenge.

So far we have talked only about camera systems. Now let us talk about scanner systems. The scanner most widely in the news these days is the one aboard NASA's Earth Resources Technology Satellite. In that system, a beam of light is broken up into four spectral bands, three in the visible portion and one in the near-infrared. The amount of energy in each spectral band is sensed and converted into a voltage which is proportional to the amount of energy. A number representing that voltage is then radioed back to earth and stored in digital form on magnetic tape. One form of processing is then to read the numbers off the tape,

Fig. 25. False-color infrared photograph

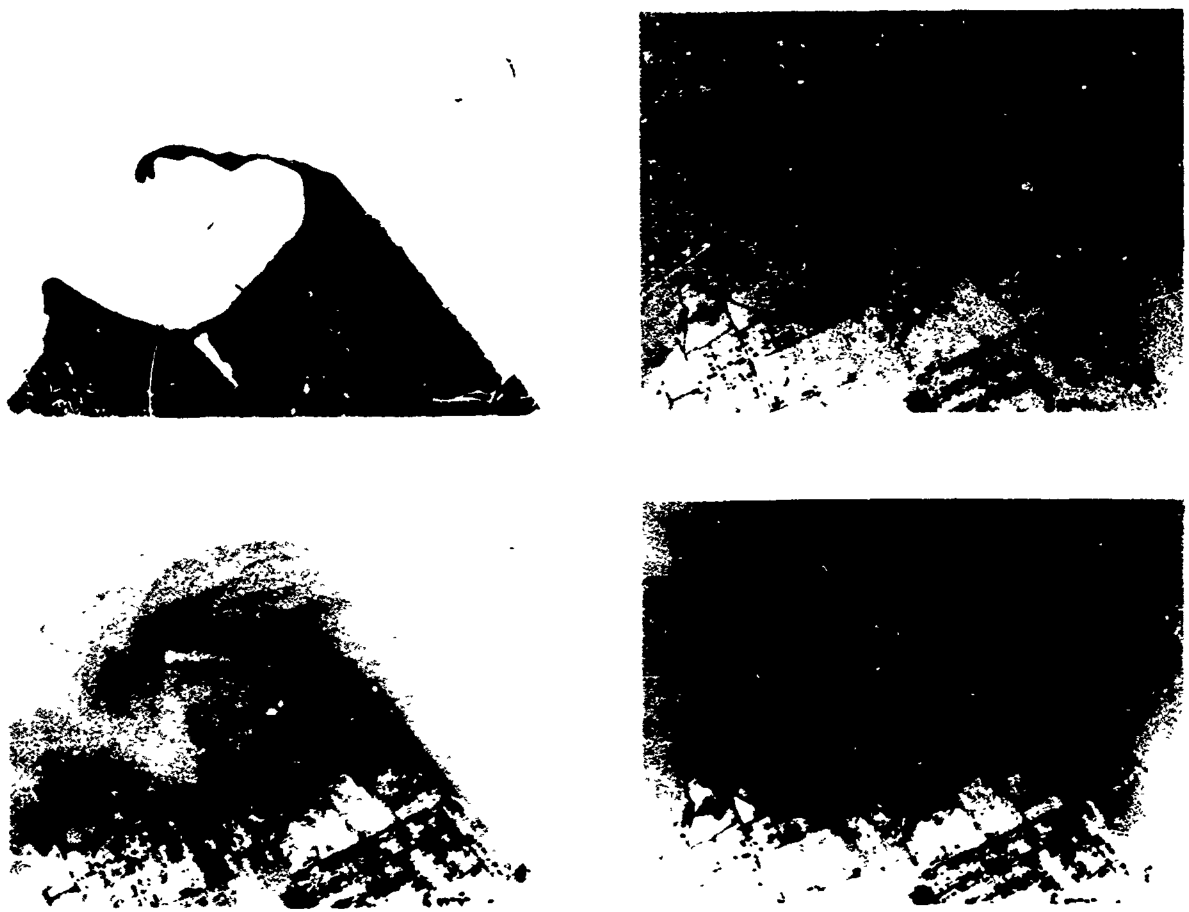


Fig. 24. Example of photographs that record spectral information

convert them back into light which is proportional in brightness to the number, and use that light to expose a piece of film, thus recreating a hard-copy picture. An example of the resulting pictures is illustrated in fig. 25. Each represents a spectral band. It should be noted that this is a scanner-produced equivalent of the I^2S system. There are a number of advantages: One is that the "picture" can be stored on a reel

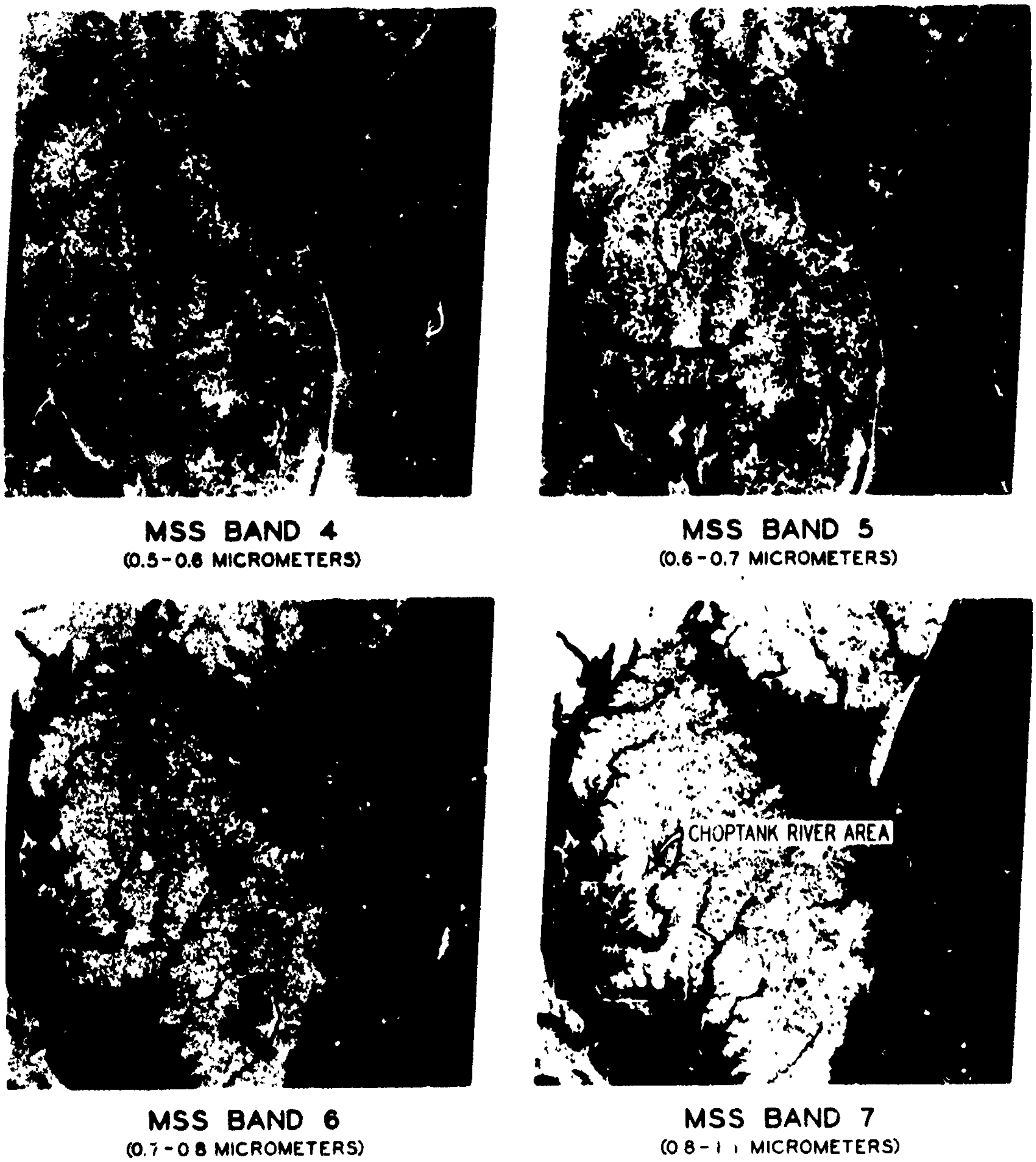


Fig. 25. A portion of Chesapeake Bay study area viewed from Earth Resources Technology Satellite (ERTS-1)

of magnetic tape. We will expand on this later. Another is that it is a good bit easier to achieve sharp separations between the spectral bands. The major disadvantage is that the resultant images are not as sharp as can be obtained with a camera.

Scanners can also be designed to operate in the infrared region, including what is usually called the "thermal infrared" band which, depending upon definition, may range from about 3.0 μm to 1000 μm or more. The usual operating range is between 8.0 and 14.0 μm. For all practical purposes these devices measure the <u>temperatures</u> of objects, and thus what one obtains is a "heat picture." Thus, any phenomenon which could be expected to show up as a difference in temperature is fair game. Probably the most common use is to map the "heat plumes" of power plants in rivers and lakes, but there are many other uses as well. The illustration (fig. 26) shows the appearance of a landscape as revealed by an infrared scanner. High temperatures are light, low temperatures are dark. Wet soils, being cool, are dark.

Please note that in this image the water behind the dam is light-toned, indicating that it is warm in comparison to the soil in the dam. This is because the data were obtained in the early morning hours, so that the soil had had most of the night to cool off. Had the data been taken in the afternoon, the situation would have been the reverse; that is, the water would have shown dark (that is, cool) against the light-toned (that is, warm) soil. At least two points need to be made. First, a mission including the use of thermal infrared should be flown at a time carefully selected to maximize temperature differences; and second, the best time can by and large only be selected on the basis of really detailed ground control. That was one of the reasons why we developed the micrometeorological station we discussed earlier.

Selecting the optimum time is <u>not</u> a trivial task. For example, here (fig. 27) is an array of thermistors set out to monitor soil, vegetation, and air temperatures through several diurnal cycles for the sole purpose of selecting a time when a very subtle temperature variation would be at its maximum.

Radar systems are also scanners, but they employ comparatively

Fig. 26. Image produced by thermal infrared scanner

Fig. 27. Setting a thermistor array for selecting optimum remote-sensor data acquisition time

long wavelengths, ranging from about 1 mm to about 1 m. They also differ from all other systems discussed up to now in one important particular: The energy source is produced artificially. In effect, a "searchlight" beam of radio energy is swept across a scene, and the reflected energy is recorded. This energy is converted to a voltage, the voltage is converted to light, the light is used to expose a piece of film, and presto, we have a hard-copy picture! Alternatively the voltage can be used to drive a television viewer, and we can then take a picture of the television image. In either case, the resultant picture looks like this illustration (fig. 28). One overwhelming advantage is that the radiation penetrates clouds and haze, so products can be obtained in any weather (within reason). In addition, since the sensor system carries its own source of illumination, one can get pictures at night. The disadvantages are that the resolution is relatively poor, and it takes a very skilled interpreter to use the data really effectively. For example, the brightness is largely a function of the angle between the reflecting surface and the emitter/receiver. To the uninitiated, this can be a bit disconcerting.

There is also a class of scanners that, as indicated earlier, do not lend themselves to image formation. They can, however, be arranged to provide information along a single line, a very narrow zone, or even at a point. One example of this class is the laser profilometer (fig. 29). This device is essentially a range-finding device; it projects a laser beam to the ground, accepts the energy reflected from the ground, calculates the round-trip distance, and records that value at very short time intervals on magnetic tape. In effect, the result (fig. 30) is a profile of the reflecting surface. Please note that it is not necessarily the topographic surface; the device is pretty stupid and measures the distance to whatever reflects the beam. It may be the soil surface, but it can also be a leaf, the top of a fencepost, or a layer of water vapor. Nevertheless, it can be an extraordinarily useful device if its idiosyncrasies are understood.

Another example is this gadget. What you are looking at (fig. 31) is a picture of a truck-mounted version of a device intended to be

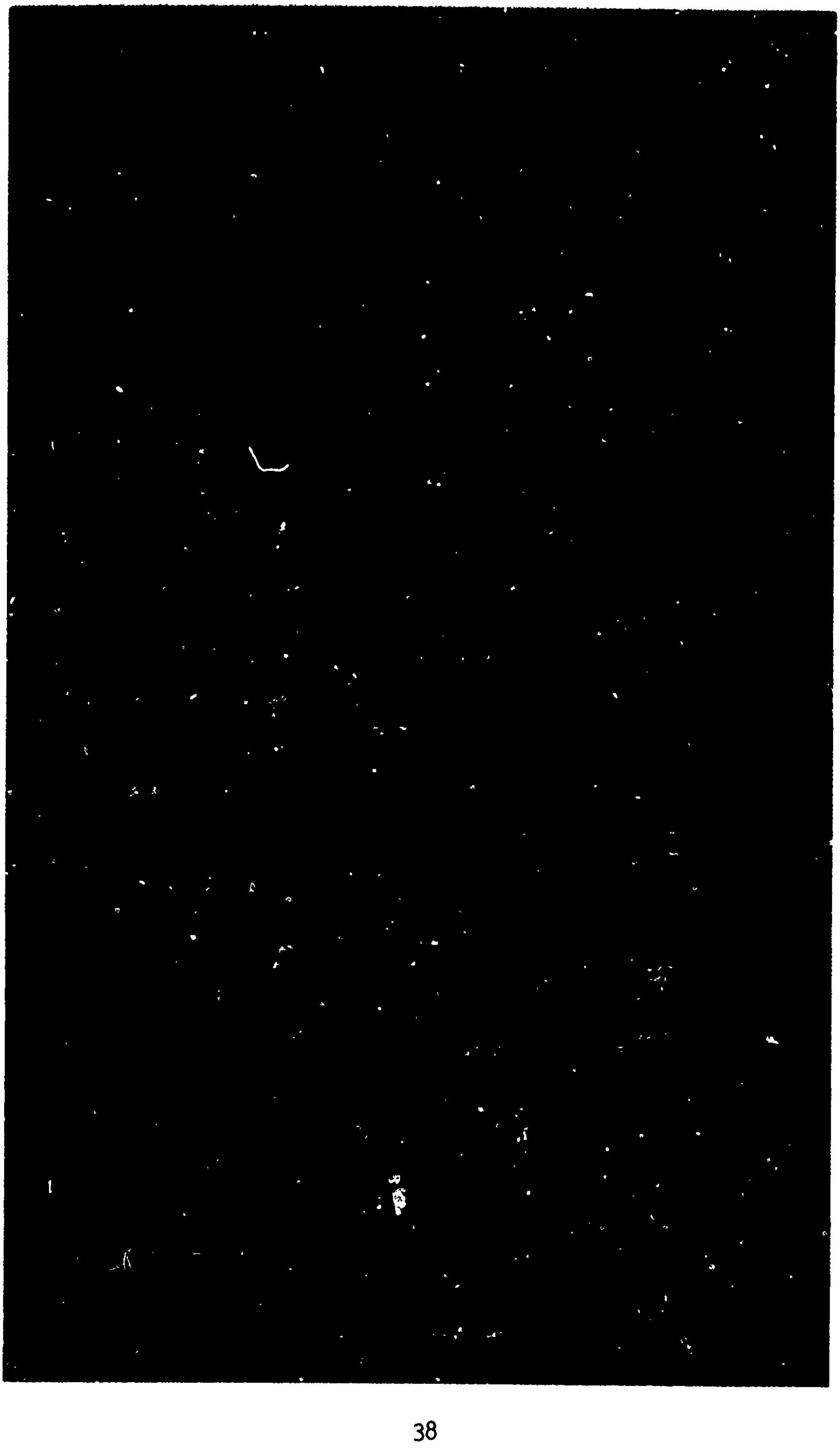


Fig. 28. Image produced by Side Looking Airborne Radar (SLAR)

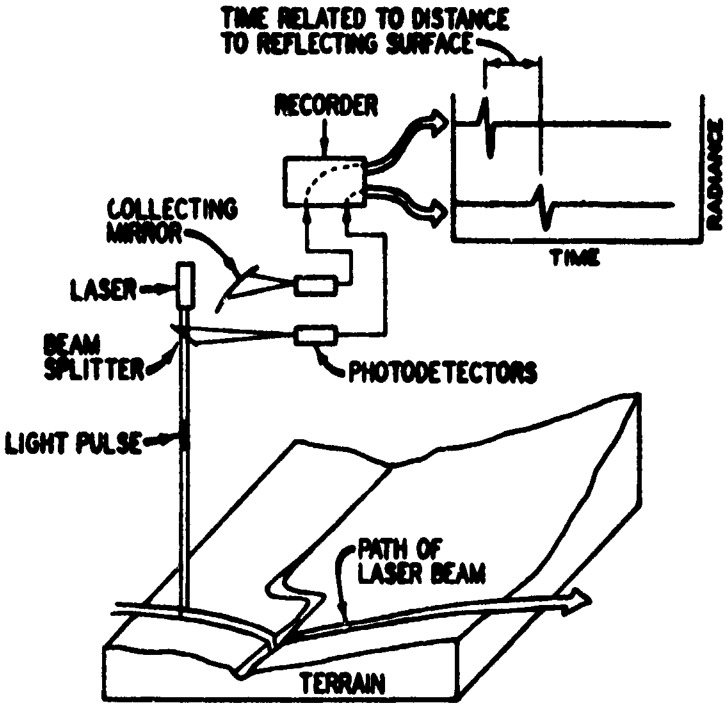


Fig. 29. Operation of a laser profilometer

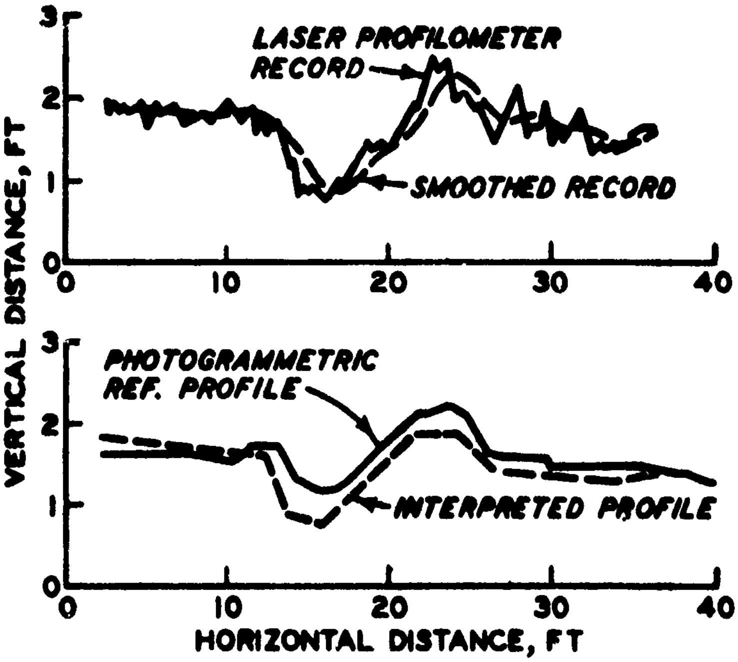


Fig. 30. Laser profilometer output compared with photogrammetric reference and interpreted profiles

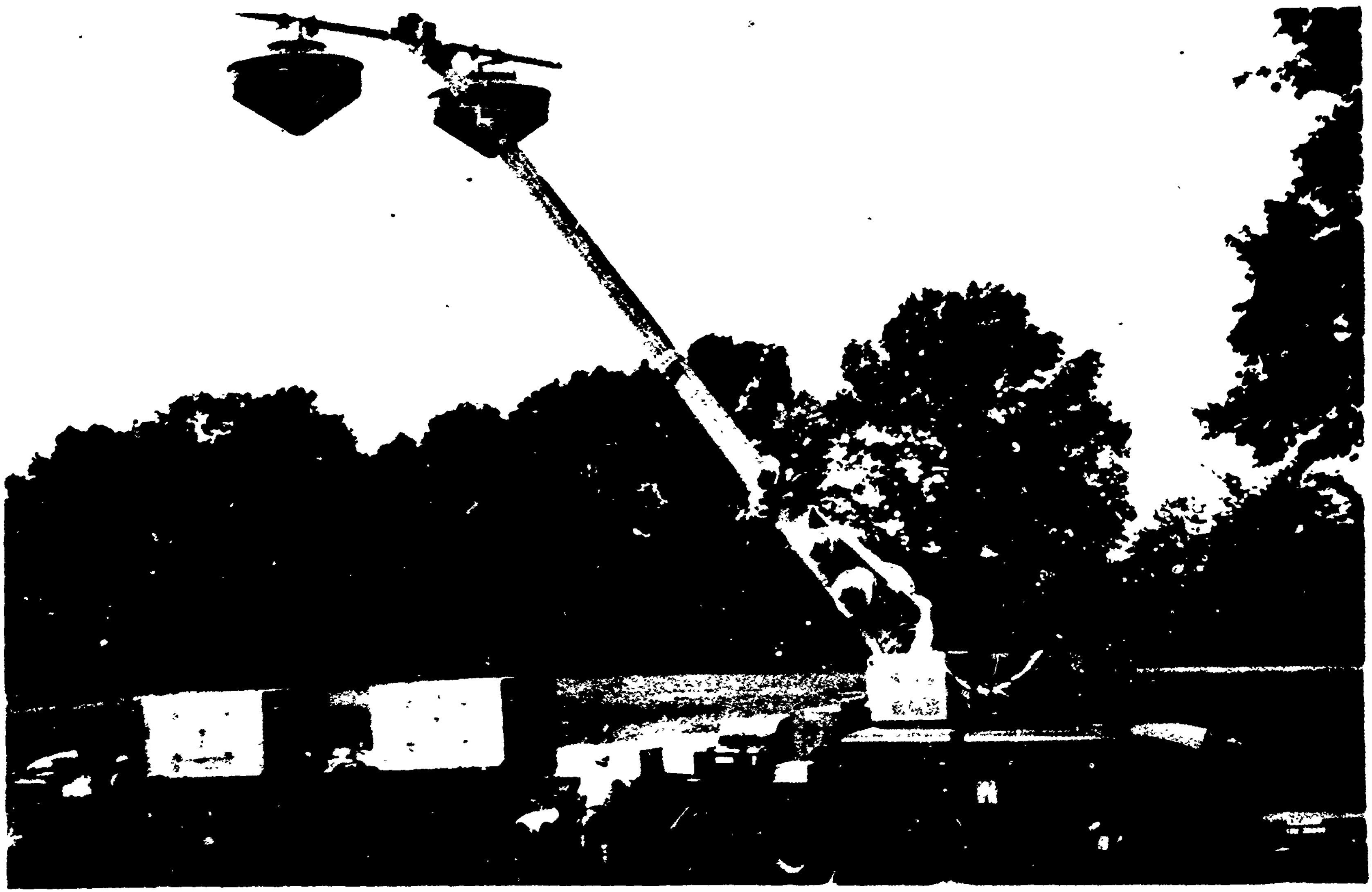


Fig. 31. Swept frequency radar mantel and truck

mounted in a helicopter. It radiates radar frequencies, which are swept through a broad spectrum of wavelengths, and records the reflected signal, which looks rather like the diagram in the center of fig. 32.

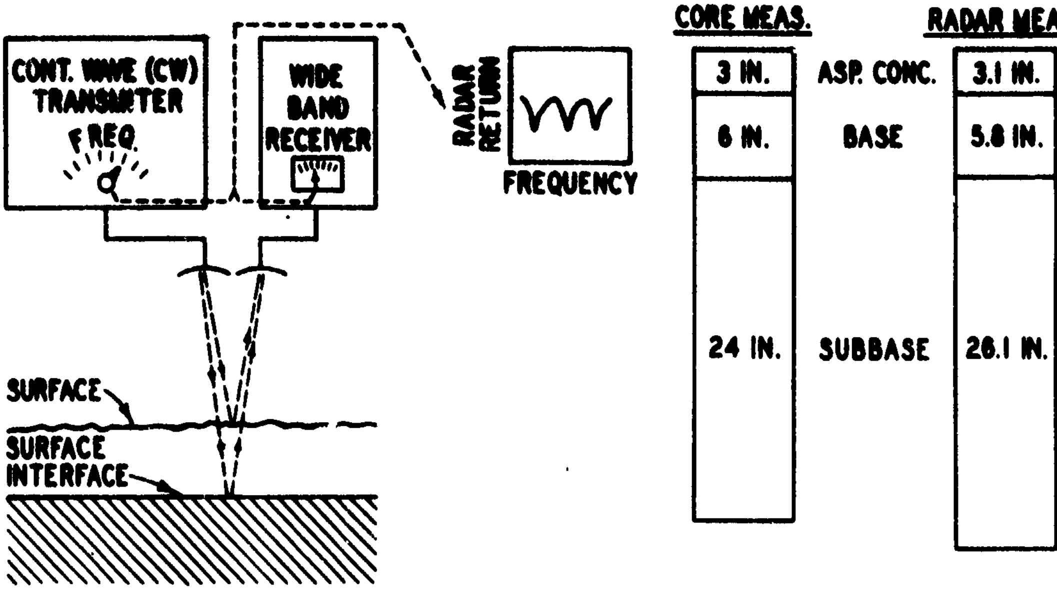


Fig. 32. Swept frequency radar studies

Properly processed, the signal will yield surprisingly accurate estimates of the thickness of soil layers, pavements, and the like.

Finally, just to make the point that a remote-sensing system need not necessarily use electromagnetic waves, here (fig. 33) is a product that uses acoustic waves penetrating water and bottom sediments. What you are looking at is a record of the bottom profile and some of the subsurface stratification along a shore-to-shore transit. Unlike the remote-sensing systems previously described, the device that produces this record is in the WES inventory.

A few paragraphs back, we said that there were some advantages in obtaining remote-sensing data in digital form as opposed to pictorial form. Basically, the reason is that data in digital form, being numerical, can be operated on by numerical or mathematical processes. For example, the laser profilometer record shown previously was pretty "noisy," but it is quite straightforward to mathematically "smooth" the record, thus making it far easier for a mere mortal to interpret. Later

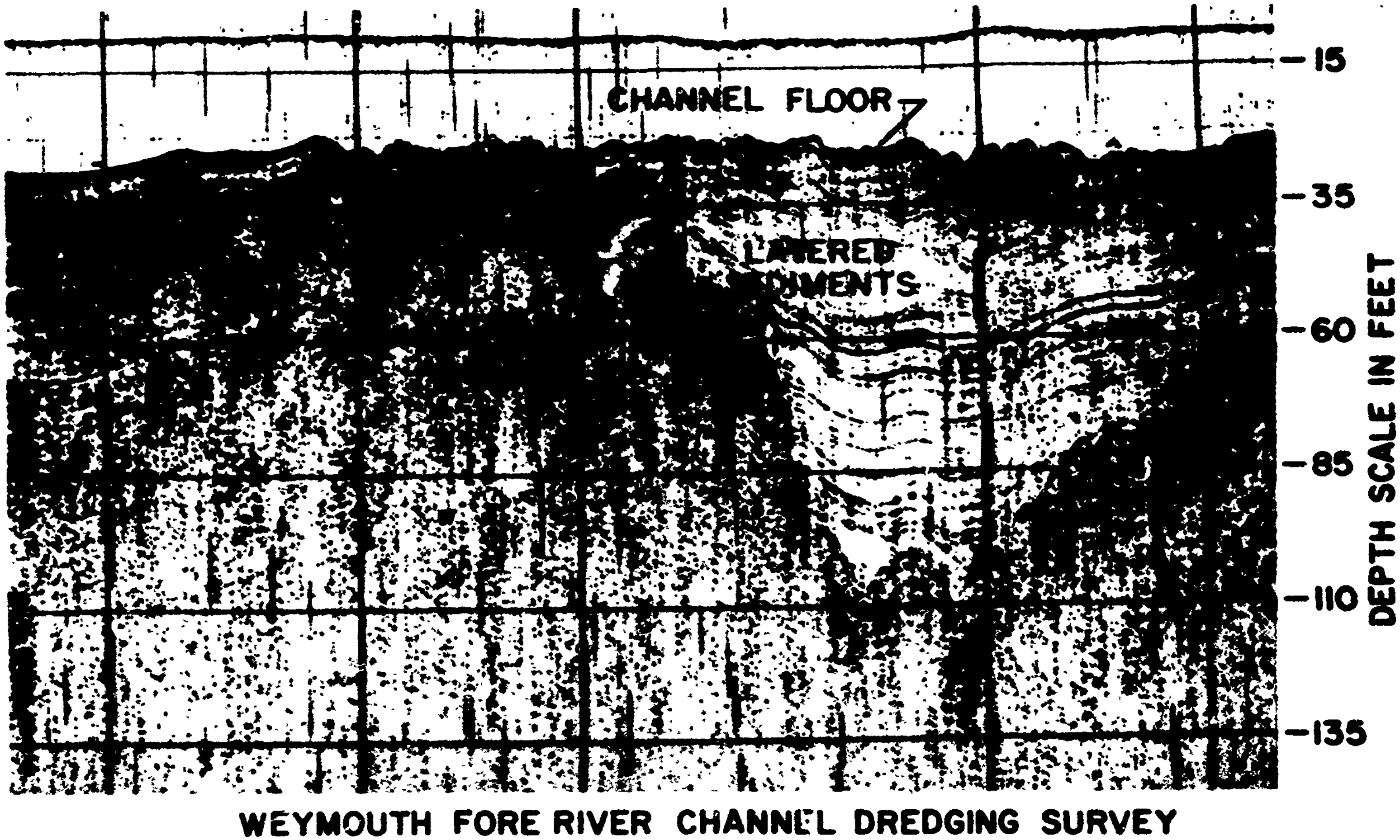


Fig. 33. Output of river bottom-sub bottom acoustic profile

in this discussion other kinds of mathematical processing will be described, and perhaps the advantages inherent in digital records will become more apparent.

While WES does not have much in the way of equipment to obtain remote-sensing system products, we have nevertheless devoted a good deal of effort to the analysis of those systems. Aside from the simple desire to utilize these products as effectively as possible, our motivation was a desire to optimize their use. The discussion up to this point was intended in part to demonstrate that the utility of sensor systems is variable. Some sensor systems are good for acquiring one class of information, but not for others. For example, thermal infrared sensors are great for analyzing thermal plumes from power plants, but they are not much good for analyzing the state of health of plants in a forest; that's a job for a sensor that uses the near-infrared spectral band.

Furthermore, some sensor systems are good for obtaining certain kinds of information, providing that they are flown at the right time of day and under the right kind of weather conditions. The point is that acquiring data by remote sensing requires that the kind of sensor and the mission profile (that is, specification of time, flight altitude, etc.) be carefully matched to the job in hand. The question is: Is it possible (and practical) to design one's use of remote sensor systems? Up to very recently, we, like everyone else, depended upon experience and intuition. We, like everyone else, had our share of failures.

Our response to this was to write a mathematical simulation model that predicts whether a given sensor system will be able to "see" a given object on the ground under a given set of light and atmospheric conditions. The model starts (fig. 34) with sunlight above the atmosphere, computes the attenuation of that light as it passes through the atmosphere, subtracts a certain proportion of it as it strikes and reflects from the object of interest, calculates the attenuation of the residual light as it moves out to the sensor and accounts for what remains as it passes through lenses and filters, and predicts grey

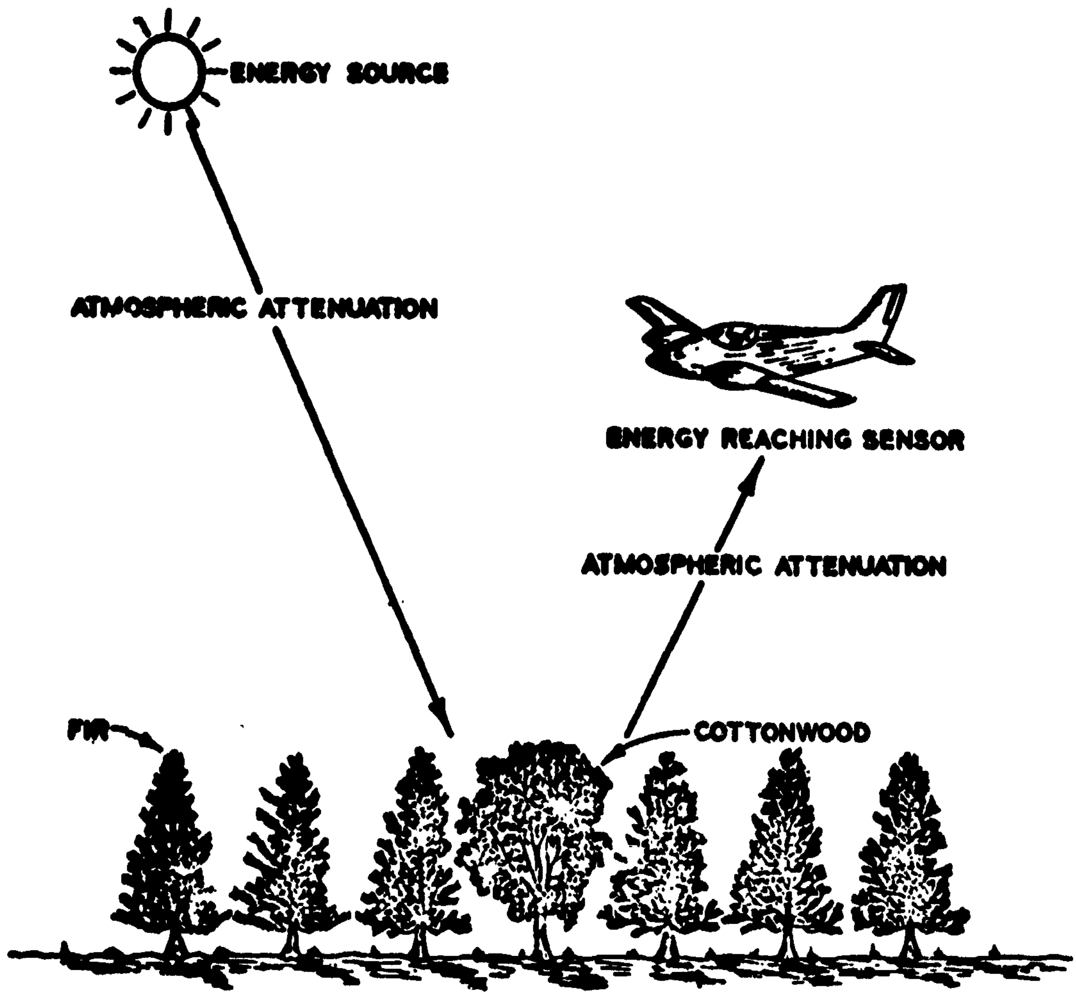


Fig. 34. Illustration of spectral component of remote-sensing simulation model

level in the film or voltage output of the photoelectric cell in the scanner. This gives us the capability of comparing two side-by-side objects and determining whether a given sensor system will be able to tell them apart. The output (fig. 35) is a table. To use the table, look for the highest positive value in the last column. The film and filter specified in the first two columns constitute the optimum combination. That is, the use of that combination will, under the specified atmospheric conditions, provide the highest probability of being able to discriminate between the two objects.

Confusing? Well, suppose that the problem facing us requires

FILM	FILTER	VISIBLE FILMS FEATURE EXPOSURE (MCS)	VISIBLE FILMS BACKGROUND EXPOSURE (MCS)	IR FILMS FEATURE EXPT FOR D=1.0 (SEC)	IR FILMS BACKGROUND EXPT FOR D=1.0 (SEC)	FEATURE DENSITY (DF)	BACKGROUND DENSITY (DB)	TF-TB	DF-DB
2402	12	0.044627	0.012246			1.352252	0.461762	-.300896	0.890490
2403	12	0.016042	0.004402			1.634589	0.632725	-.209761	1.001865
2402	47B	0.002382	0.000737			0.067276	0.050000	-.034757	0.017276
2403	47B	0.001115	0.000345			0.262955	0.100000	-.240513	0.162955
2402	58	0.040088	0.014555			1.227427	0.525250	-.239232	0.702177
2403	58	0.019214	0.006976			1.678994	1.035893	-.071226	0.643101
2402	25A	0.024675	0.004571			0.803553	0.094642	-.646991	0.708911
2403	25A	0.011826	0.002191			1.575568	0.383988	-.386486	1.191580
2402		0.030863	0.008805			0.973744	0.328322	-.363314	0.645422
2403		0.014793	0.004220			1.617095	0.612286	-.228033	1.004809
2448C		0.295361	0.084267			0.706958	1.283197	0.144259	-.576238
2448Y		0.295361	0.084267			0.511843	1.146129	0.236293	-.634287
2448M		0.295361	0.084267			0.572770	1.183197	0.201857	-.610426
2443C				0.001134	0.002719	1.000000	0.240540	-.474725	0.759460
2443Y				0.000642	0.001887	1.000000	0.200000	-.530957	0.800000
2443M				0.000385	0.002375	1.000000	0.200000	-.530957	0.800000
2443C	12			0.001639	0.003705	1.000000	0.291313	-.411313	0.708687
2443Y	12			0.001315	0.003831	1.000000	0.200000	-.530957	0.800000
2443M	12			0.000473	0.003134	1.000000	0.200000	-.530957	0.800000
2424	12			0.000173	0.000339	1.000000	0.414139	-.285355	0.585861
2424	25A			0.000180	0.000347	1.000000	0.427706	-.273503	0.572294
2424	87C			0.000010	0.000014	1.000000	0.678232	-.109782	0.321768
2424	89B			0.000248	0.000383	1.000000	0.624311	-.137914	0.375689

LEGEND

FEATURE:DOUGLAS FIR
BACKGROUND:ALPINE FIR
ATMOSPHERE:MIDLATITUDE SUMMER   HAZE-5 KM
ZENITH ANGLE: 30 DEG.
SENSOR ALTITUDE: 1.50 KM

Fig. 35. Computer output for selection of optimum remote-sensing system

that we be able to identify differences in soil moisture of 10 percent. Knowing this, we could measure the reflectances of soils at 10 percent, 20 percent, 30 percent moisture contents, and so on. These values can be inserted into the simulation models and the mathematics will identify those sensor systems *and* those atmospheric conditions that will result in detectable differences in the sensor product. This gives us a basis for going to a contractor and saying: "Use film type X at an exposure speed of y msec, and fly over the target at 1500 hours on August 27 (assuming visibility at ground level is 10 km or more) at an altitude of 6000 m."

Data manipulation

The fourth of the six processes essential to successful use of remote-sensing systems, namely data manipulation, is widely honored in the breach. It seems to us that there is a myth afoot in the land, to the effect that one's problem is over with the delivery of the pictures. Nothing could be further from the truth. Having obtained the pictures, we now have the problem of extracting from them the information we need. But before this process can start, it is often necessary to perform some rather elaborate preparatory exercises to get the remote-sensor products into a form suitable for interpretation or analysis. Sometimes this is both time-consuming and costly.

Let us begin at the most elemental level. Let us assume that our problem involves some regional relationships, and that we need something like a synoptic view of the whole region. Let us further assume that we have used a camera sensor at relatively low altitude, so that we have a stack of pictures which collectively cover the area. Obviously the *first* thing to do is to assemble them into a mosaic, so that the entire region can be looked at as a whole, as in fig. 36. If this is an *uncontrolled* mosaic (that is, one in which exact positional fidelity is not required), this may be a matter of a few minutes. But if it is to be a controlled mosaic (that is, one in which all points are in correct planimetric relationship to each other), this process may require the labor of days or even weeks. The amount of time that is required is a function of the degree of accuracy required and of the

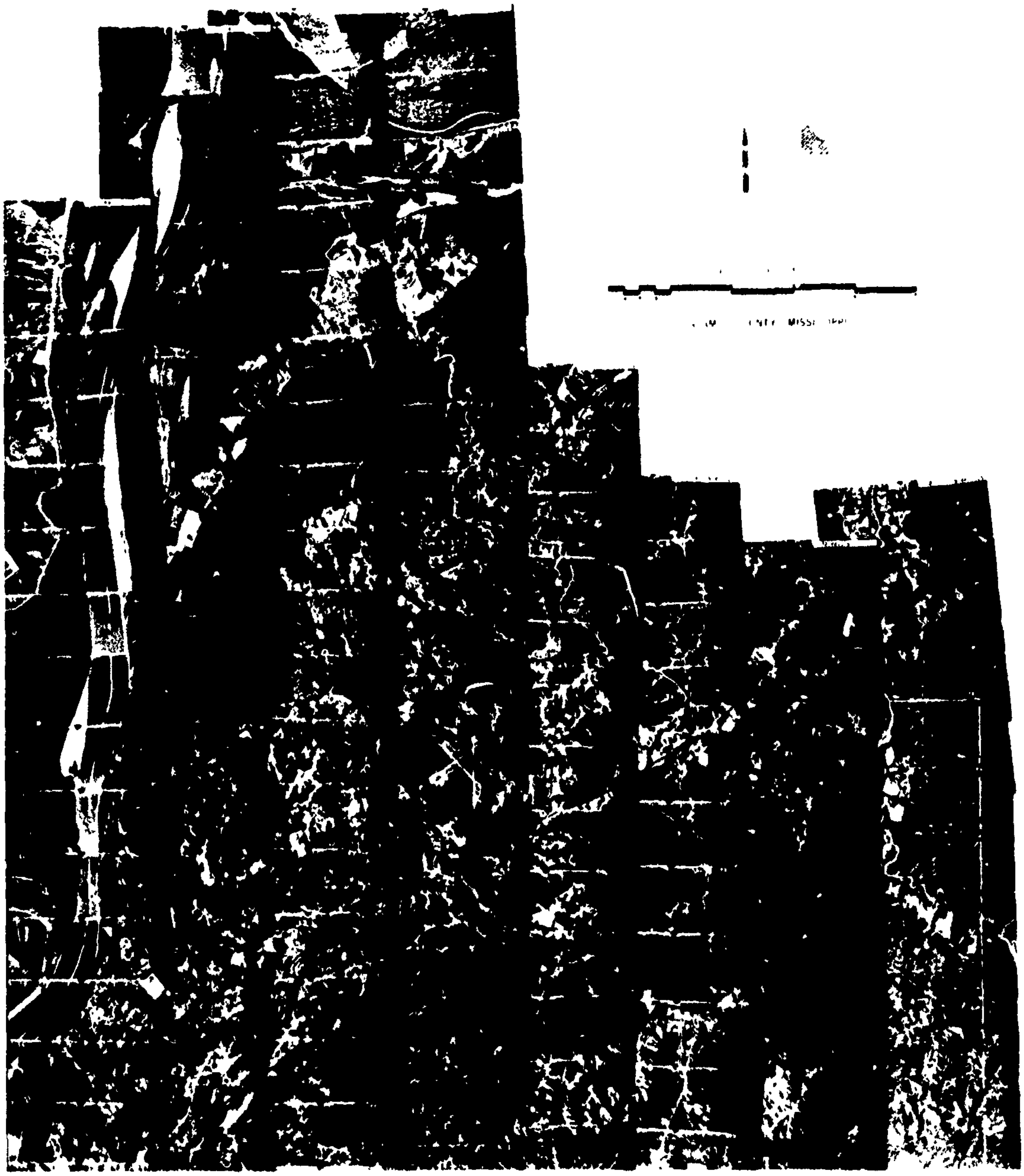


Fig. 36. Uncontrolled photo mosaic

skill of the person doing the work. The point is that, even if the only utilization of the remote-sensor products to be made is just classical photointerpretation, there is inevitably a certain amount of preparation required before the photointerpreter can get to work.

There are, however, some far more complex requirements which have evolved because of recent advances in what might be called automated interpretation. You will recall that a few paragraphs back we said that data from scanner systems could be recorded in digital form on magnetic tape, and that the first and primary product of the multispectral scanner aboard ERTS was such a tape. It turns out that the recording format used on those tapes is quite complex. It is, as a matter of fact, so complex that reading those tapes requires a computer program that is a long way from trivial. We were, after NASA itself, one of the first, if not the first, organizations to be able to read those tapes. And we have found it necessary to add some refinements that go beyond those furnished even by NASA. The problem is a bit complicated, but in general it has to do with the fact that the numbers on the tapes are records of the output voltages of the sensor system in each of the four spectral channels. These voltages are obtained by amplifying the very weak signals produced by the individual sensing elements in the sensing system. The basic problem is that the degree of amplification applied to each channel is unique to that channel. The result is that all four images reconstructed from the recorded data have approximately the same average density, regardless of the actual radiance within each channel. The point of this is that the four images as printed and distributed by NASA do not contain valid spectral data. But all is not lost, because the numbers on those original tapes can be converted back into true radiance values in each channel, but the process is not simple. It cannot be done by analysis of the images; it can only be done mathematically using the original digital tapes. So far as we know, WES is one of a very few (and perhaps the only) organizations that can perform this operation on a routine basis. The point here is that, in order to use ERTS spectral data effectively, a massive amount of manipulation of those data was required before analysis could begin.

However, the fact that very large amounts of data were handled does not imply that a large computer was used. To process all four channels of ERTS data for one scene (which is an area of about 10,000 square miles), 31,366,400 pixel numbers had to be processed in several different ways. This is a large data file by almost any standard. Yet, we did all of our ERTS data processing on a PDP-15 computer with 16,000

18-bit words of core memory. So we would like to emphasize once again that, while we use a great deal of computer processing, we do not use a large machine. In fact, it is about as small a machine as one can conveniently get.

Now let us return our attention to photographic methods of storing spectral data. You will recall that one method is by use of the I^2S camera, which produces four images, each in a more or less discrete spectral band. Please remember that the pictures are black and white, but that the energy which produced them was separated into color bands. Thus, one picture of the set was produced by blue light, another by green light, and so on. The density of the image is thus a measure of the amount of energy in each wavelength band. That is, it is, *if* one knows the exposure time, the camera aperture, and the film speed used in each of the four images.

The question is: How can the pictures be converted into quantitative spectral data? This can be done by a process involving a scanning microdensitometer (film reader) like the Optronics device illustrated in fig. 37. This machine scans an image using an instantaneous field of view (or scanning spot) that may be as small as 12.55 μm in diameter, or as large as 800 μm. This process breaks up the original picture into pixels in a way closely analogous to the way the scanner aboard ERTS breaks up an actual view of earth. In effect, we now have a *number array* that represents a picture. The illustration (fig. 38) shows a picture and a segment of its representative number array as printed out by a line printer.

The number array is a measure of the amount of energy passing through each pixel comprising the picture; the energy is proportional to the film density, and the film density is a measure of the amount of energy reflected by the corresponding area on the ground. This means that we have a number array representing the amount of energy in each pixel in the spectral band used to obtain the image. Obviously if this process is repeated for each of the four I^2S pictures, the result will be a definition of the spectral composition of each pixel in the scene.

Once having obtained a number array on a reel of magnetic tape, a

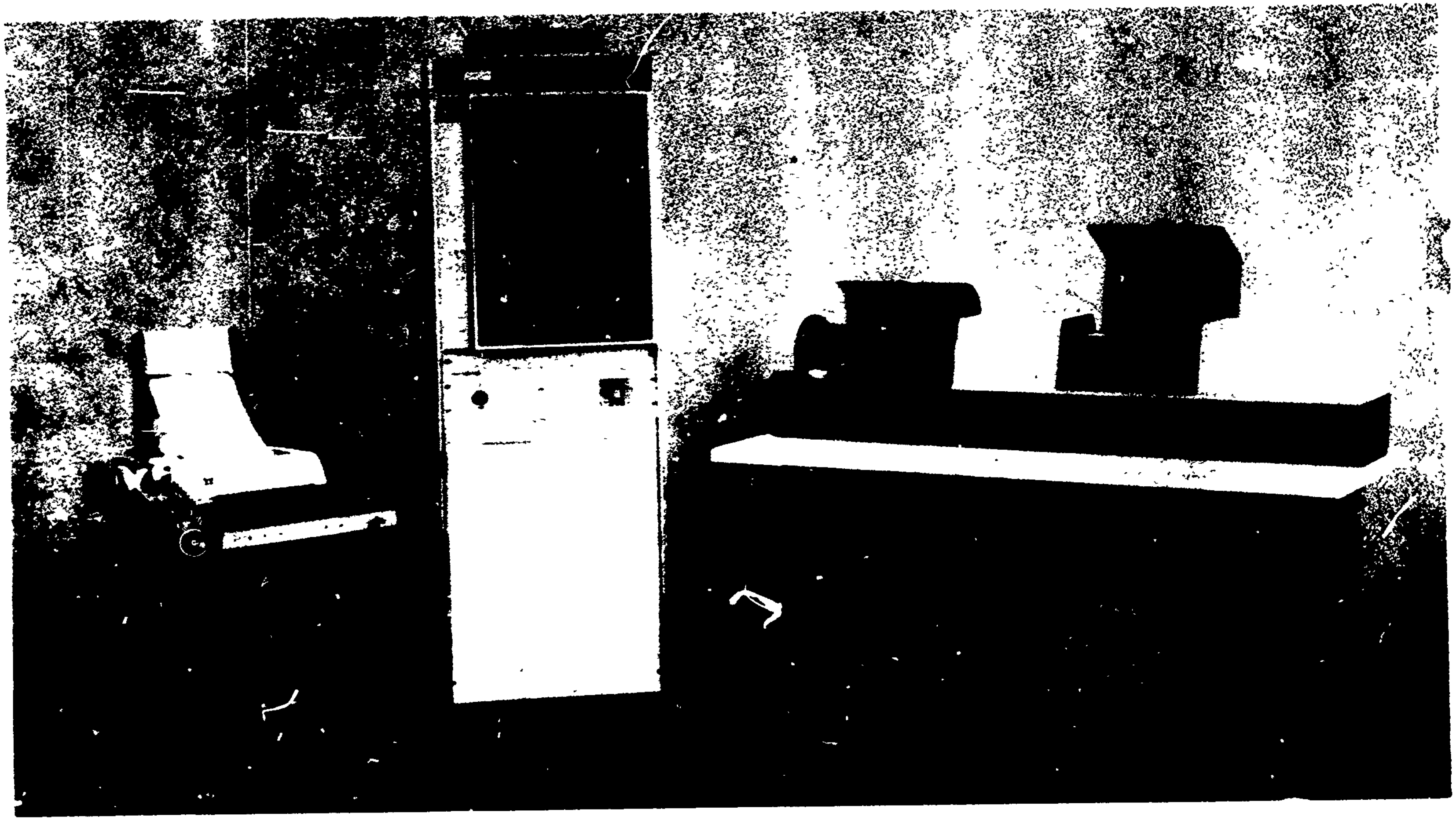
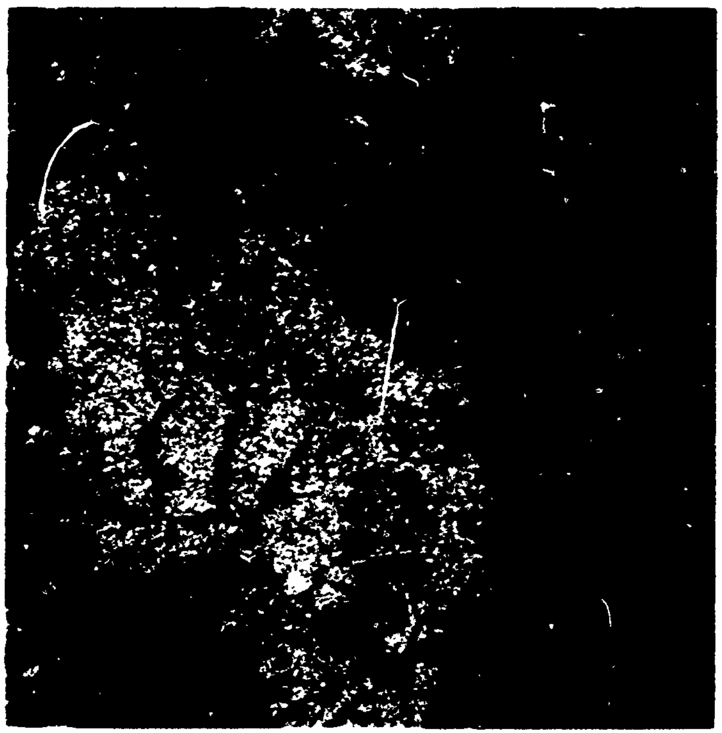


Fig. 37. Film reader writer



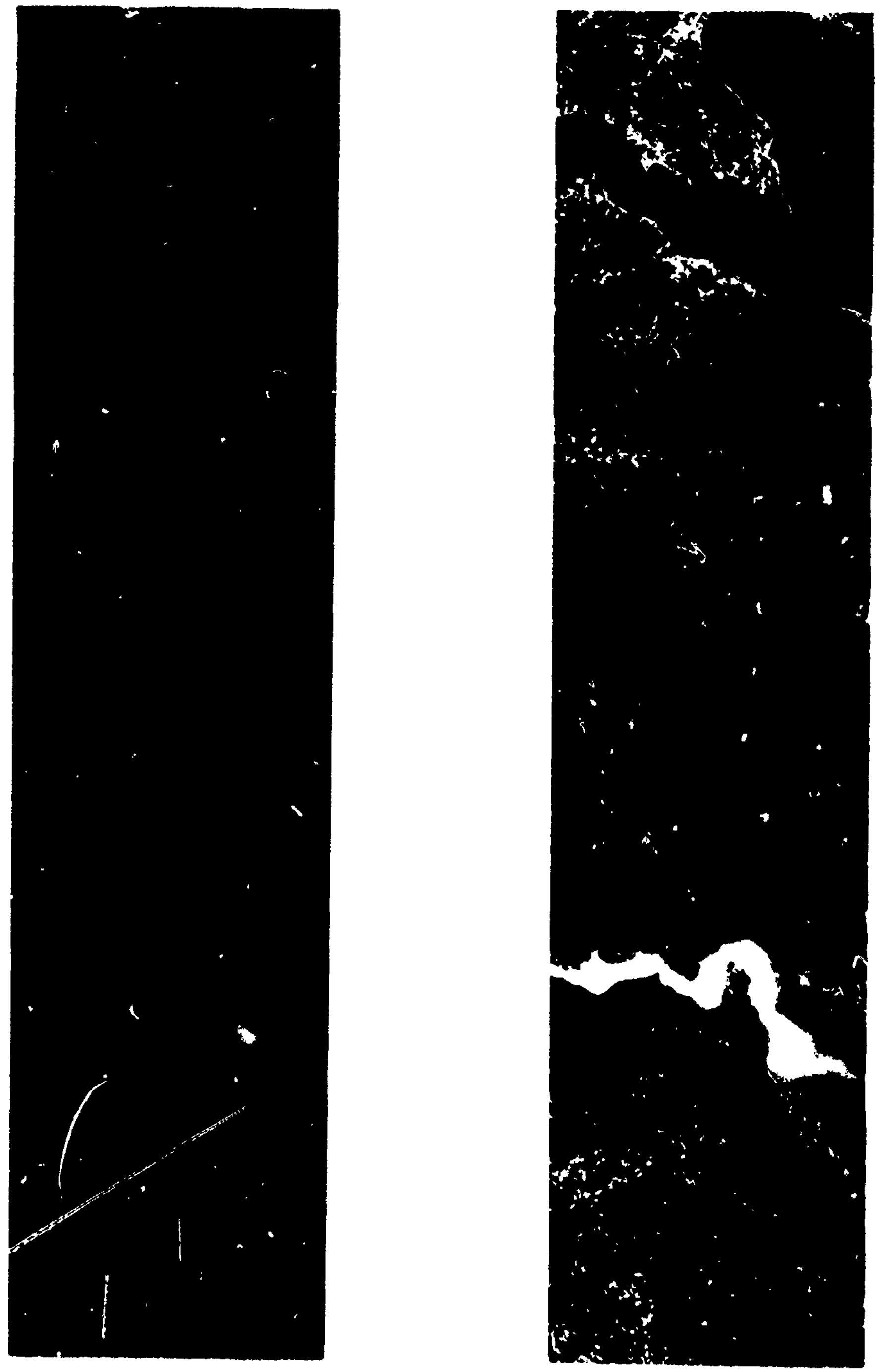
288	269	240	220	230	230	211	067	009	009	009	009	019	000	009	009	009	009	909	009
249	249	230	220	220	230	172	028	000	009	009	009	009	000	009	009	009	009	009	003
230	230	211	230	240	230	201	096	009	009	019	009	009	009	009	009	019	019	019	009
220	240	230	220	211	230	211	057	000	009	019	009	009	009	009	013	019	009	009	019
230	211	220	211	220	153	028	009	000	000	000	000	000	009	009	000	009	000	000	000
220	220	230	220	192	048	000	003	009	000	000	003	009	009	009	009	009	009	000	000
220	201	172	163	086	099	009	003	013	013	003	009	009	009	009	009	009	009	009	009
201	163	096	019	000	009	003	009	009	009	009	093	009	000	009	009	0[illegible]	009	039	009
134	153	124	033	009	019	009	000	019	009	009	009	009	009	009	009	019	019	019	019
115	038	009	019	009	019	003	019	009	019	009	019	009	019	019	009	019	019	013	009
153	067	000	000	000	000	002	000	000	003	000	009	000	000	009	009	009	000	009	009
163	105	032	009	000	003	009	003	009	000	000	000	000	000	000	000	000	009	009	009
172	036	009	000	000	009	007	009	009	003	009	009	009	009	003	009	009	003	009	009
038	000	009	000	009	039	019	003	003	000	009	000	000	000	000	003	009	019	009	009
013	009	000	000	009	013	003	003	019	013	019	019	019	013	009	003	009	019	319	019
009	019	000	003	009	009	003	003	013	009	019	019	009	019	019	003	013	019	019	009
000	000	300	000	000	000	003	000	003	003	000	009	003	000	003	003	000	003	000	000
000	030	000	000	000	033	003	013	003	004	005	003	003	009	003	003	000	003	005	003
009	003	003	030	009	009	004	003	003	004	003	009	009	003	000	003	009	005	009	003
009	003	000	000	000	039	000	000	003	003	000	009	003	009	009	003	003	003	009	000
013	003	003	013	013	013	014	019	009	013	013	003	009	009	003	003	013	009	003	009
009	003	019	013	003	019	013	013	013	019	003	004	019	009	013	009	033	003	003	019
000	003	000	003	012	009	003	004	000	003	003	070	000	009	033	003	003	003	013	076
000	000	003	000	009	033	00[illegible]	0[illegible]	003	030	030	013	003	035	036	124	124	086	036	144
003	032	003	019	009	003	003	033	003	013	033	042	124	153	153	157	153	163	172	172
009	004	004	003	003	003	074	003	004	013	076	153	153	153	172	190	182	182	192	190
009	003	009	003	009	013	013	003	003	013	115	230	201	192	172	182	211	211	192	163
003	009	013	011	019	019	003	019	003	057	153	172	201	201	192	201	201	201	201	192
003	004	000	003	009	003	002	004	022	115	153	163	172	192	192	192	192	182	201	211
000	000	049	033	000	003	000	013	105	144	124	163	192	172	201	201	211	211	220	220
003	000	009	003	005	013	013	1[illegible]	153	134	153	192	182	163	153	211	211	211	201	192
009	012	009	003	032	013	0[illegible]	112	167	124	134	153	153	192	230	211	192	172	124	105
009	003	000	013	013	019	067	163	152	167	167	172	163	211	192	153	153	067	003	019
003	013	003	003	019	025	153	230	192	172	152	167	201	220	182	084	019	009	019	000
000	009	003	009	013	124	220	201	192	153	124	192	230	211	172	096	009	009	009	000
009	000	003	004	013	036	157	157	157	172	211	201	211	211	134	028	000	600	000	000
009	013	009	009	005	019	036	220	230	201	162	211	182	076	019	003	019	003	003	009
009	009	003	003	013	009	009	033	036	174	153	076	019	003	003	003	030	019	009	028
009	003	003	003	019	013	003	003	003	003	013	013	009	009	019	005	009	013	009	003
009	003	005	019	009	009	009	003	005	013	009	009	003	003	009	009	005	009	009	009
000	009	000	000	002	000	000	000	000	000	000	009	009	000	000	009	000	000	000	009
000	003	000	000	000	003	000	000	000	003	003	003	009	009	000	000	009	000	009	019
000	000	009	000	009	003	009	003	005	009	009	000	000	009	009	009	009	009	000	019
000	003	000	003	000	009	000	000	000	003	009	009	000	009	003	009	009	009	009	009

Fig. 38. Number array representing portion of photograph

lot of things are possible. Let us mention only three. First, the exposure used to record a picture on film is adjusted to some sort of average radiance level. If there happen to be very bright or very dark patches in the scene, the detail in those areas is "lost," because the human eye can only discriminate among a relatively few densities (or, in the jargon, grey levels). If the information we want happens to be one of those patches, we're dead. The information may well be there, but we can't see it. However, the microdensitometer can discriminate among many more grey levels than the human eye, so it can "see" and assign numerical values to things lost in the bright and dark patches. It is then possible to isolate the light (or dark) patches, mathematically amplify the contrast, and reprint the picture so that the detail within those areas is revealed to the human interpreter. The reprinting is done with the same Optronics device used to scan the image in the first place. This is one example of the general process called "image enhancement" (fig. 39).

Another very useful capability is usually called "density slicing." Remember that all of the grey levels in a picture have been stored as digits on a piece of magnetic tape. Suppose that we have a problem in which the things we want to identify always present the same radiance value throughout a scene. This is easy to solve analytically; the computer is instructed to look at each value in the digital record and determine whether it matches the desired value or not. If it does not, the machine "throws it away," but if it matches, it stores the position of that pixel on a new reel of magnetic tape. We then run this tape through the Optronics picture writer, and it prints out a picture of all the areas characterized by the desired grey level. Here (fig. 40) is a picture of a small part of the Chesapeake Bay which was obtained by this process. In this case, a wavelength band was selected such that open water gave a distinctive grey level, and the mathematics "sliced" the digital record of an ERTS scene to retain the digital record for only the surface water areas.

The next capability, made possible by having a digital record of true radiance values in each spectral band, is identified by the general



BEFORE AFTER

Fig. 39. Example of image enhancement

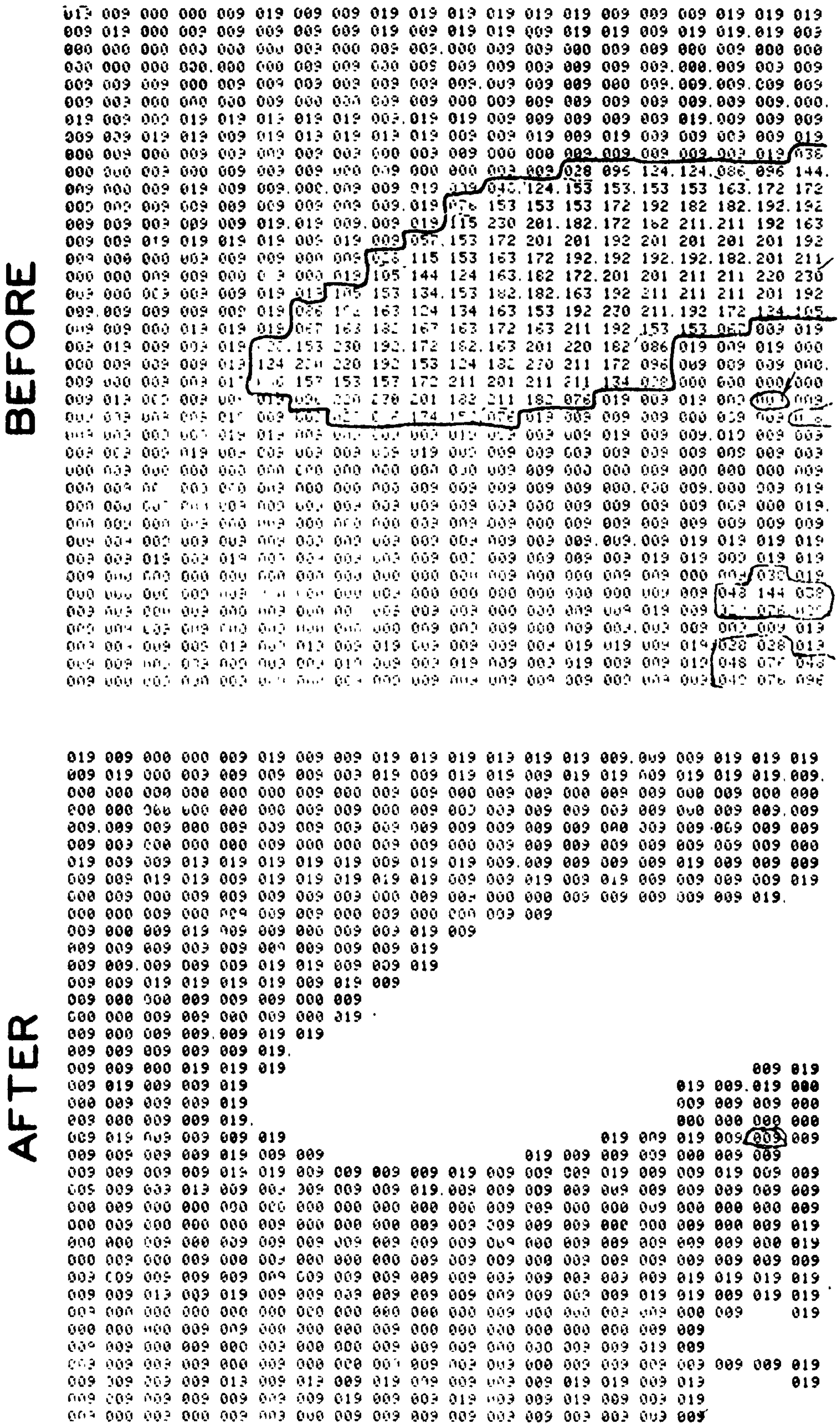


Fig. 40. Results of digital mask

term "spectral matching." This procedure is very important, since it opens the door to some quite elaborate forms of automatic interpretation of remote-sensor products. It is also, unfortunately, a bit complicated. We have already described most of the processes that go on, but for the sake of coherence, let us go over them again quickly. Start with light reflected from a small patch of countryside (fig. 41). The sensor sees

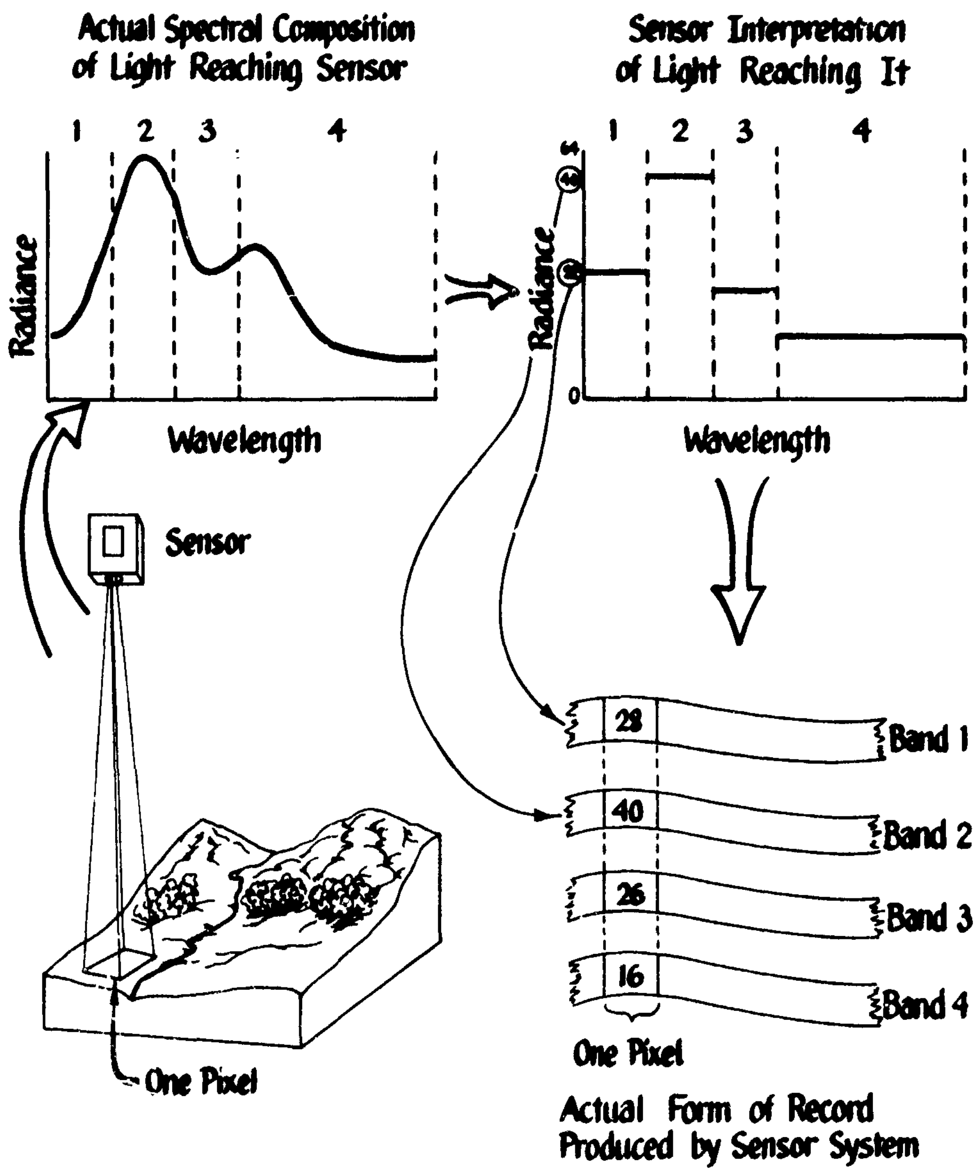


Fig. 41. Light from pixel converted to number proportional to amount of energy detected

the patch as a pixel, and it breaks up the light into (in the case of ERTS, for example) four wavelength bands. The actual light reaching the sensor is more or less a continuum of energy spread across the entire visible spectrum, but the sensor sees it as four discrete bands. It measures the total amount of energy in each band and records that value as a number proportional to the amount of energy. If we now have a sample of material in which we are interested, we could point a spectrophotometer at it at ground level and determine the spectral composition of the reflected light (fig. 42), and we could then integrate that light into the same four wavelength bands used in the sensor. This would give us a set of four radiance values representing the

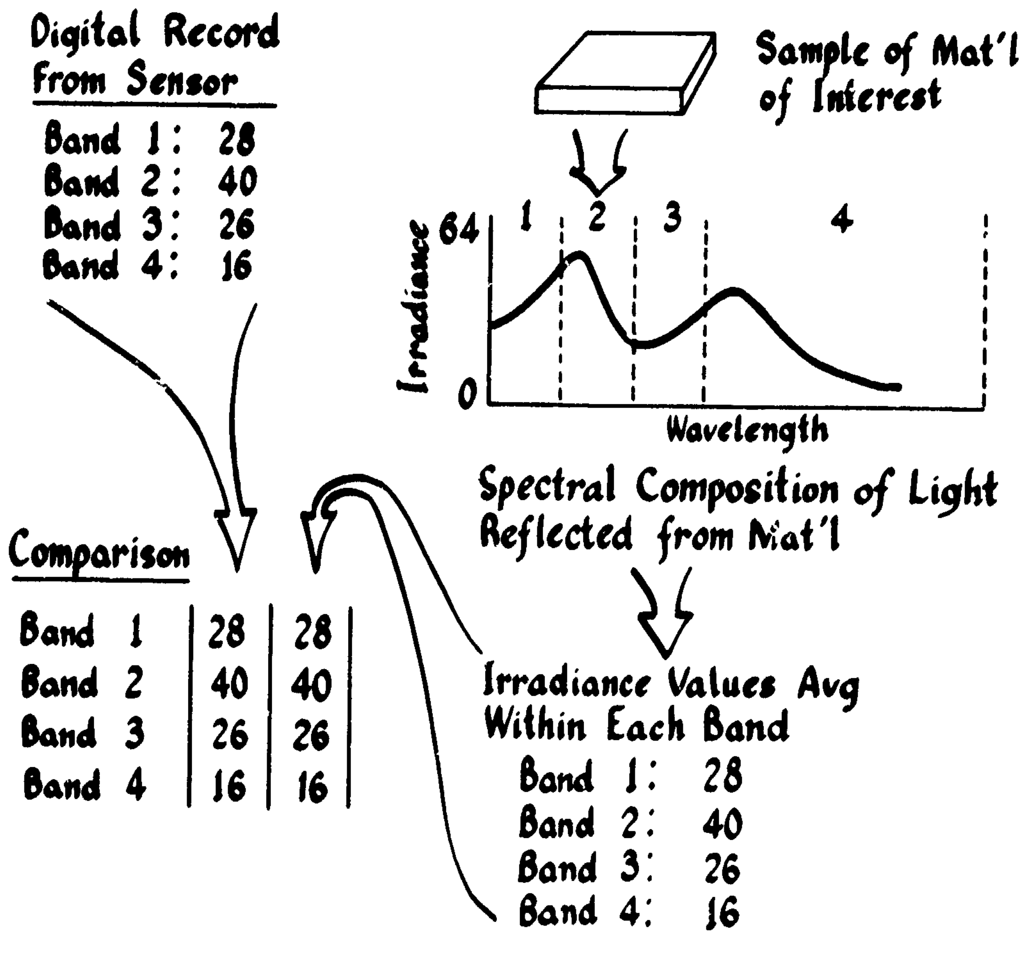


Fig. 42. Interpretation: material composing pixel on the ground is the material of interest

spectral composition of the material of interest. We can now look at the radiance values in each band in each pixel, as seen by the sensor, and compare them with the radiance values as measured on the ground. If all four of the sensor-obtained values match all four of the ground-control values, we have a spectral match, and we can jump to the conclusion that the pixel being viewed by the sensor is composed of the material in which we are interested. Unfortunately, this is not universally true, but it is a good starting place for a number of interpretive processes. Which leads us to the next of the six basic processes involved in the use of remote-sensing systems.

It should not be overlooked that the oddball sensors also have their special data manipulation requirements. For example, a gamma ray sensor produces a string of numbers, each of which represents the number of gamma ray particles of specific energy level per unit of area. In tabular form and with the energy level information unrelated to the source atom, these data are pretty hard to interpret. But, if those same data are sorted out and plotted as a map (fig. 43), the product can be quite easy to interpret.

Information extraction

When all of the preliminary data manipulation procedures have been completed, the true work of information extraction can begin. This can be a rigorous mathematical process, using techniques like density slicing and spectrum matching, or it may be achieved by essentially subjective procedures such as classical photointerpretation. Or, if the desired data consist of things inherent in the three-dimensional geometry of the landscape, information extraction can be achieved by photogrammetric processes. More often than not, it turns out that all three processes are required. In view of this, an example or two of each is included in the following discussion.

Let us first consider an example of spectrum matching. One problem facing the engineering community (and many others) is that of determining the distributions of suspended sediments in rivers, lakes, and estuaries. Since suspended sediment consists largely of little chunks of solid material distributed through a volume of water, it can confidently

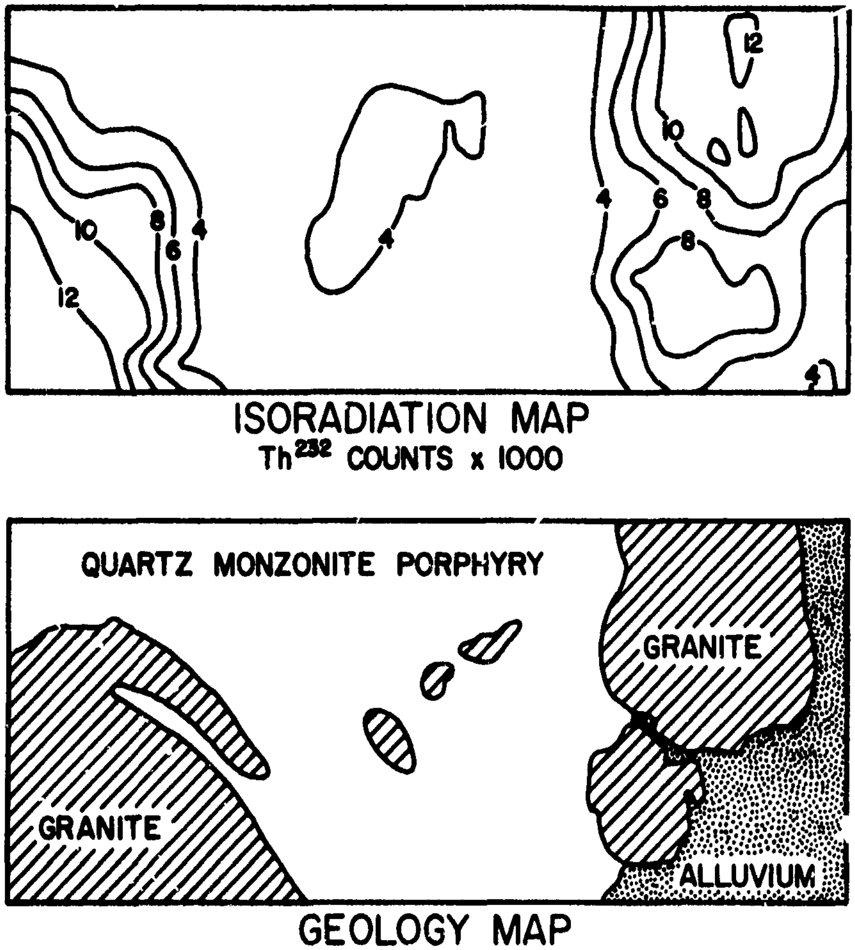


Fig. 43. Correlation between gamma radiation and rock types; Tyrone, N. Mex.

be anticipated that the amount of light reflected from the water body will be proportional to the number of suspended particles, and that the spectral composition of the reflected light will be related to the kind of material comprising the particles. Thus, if the spectral composition of a sample of water containing suspended sediments was measured, the data needed to perform a spectral match with ERTS sensor data would be in hand. The illustration (fig. 44) shows the correlation between concentration of suspended sediment in the York River and processed spectral data in three of the four ERTS spectral channels.

The "error band" shown on the figure has nothing to do with the

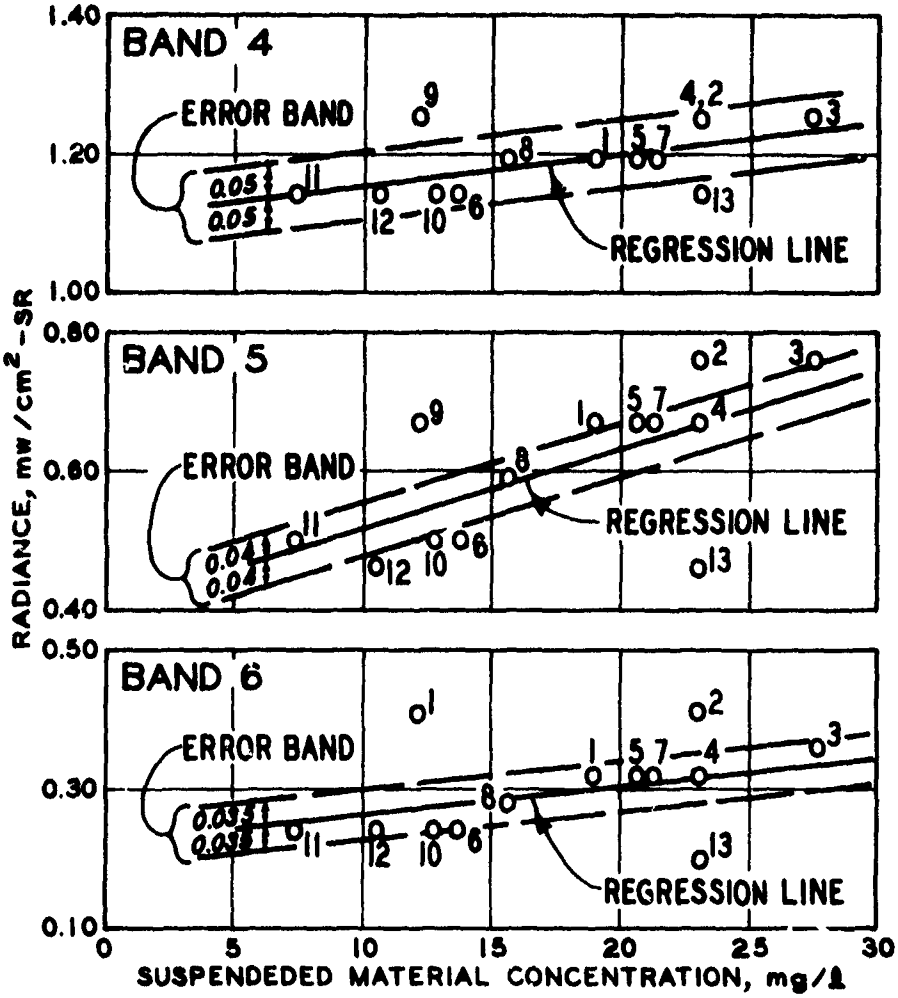


Fig. 44. Correlation of suspended material concentration and spectral radiance

correlation statistics. It is the range of possible error in the ERTS radiance values and represents primarily electronic system error. In plain talk, that means that any given ERTS radiance value can be in error by as much as plus or minus 2 percent. One way of looking at this is to consider a "perfect" correlation to be one in which all of the ground control data points would fall inside the instrumental error band. And, in fact, it should be noted that they very nearly do. The apparent anomalies, as illustrated by data point 13, turned out to be locations where a different kind of sediment, with different spectral characteristics, was present. The implication is that the method is sensitive enough to discriminate among types of sediments, if those types are characterized by different spectral reflectances. The correlation is so tight that we feel quite confident that we can "measure" suspended sediment concentrations using multispectral data. We are, in fact, using this technique to define the patterns of sediment distribution in some estuaries bordering Chesapeake Bay. An example of a picture produced by this technique is shown in fig. 45.

The density slicing technique is being used on a large scale to map the distributions of water bodies using ERTS data. Since near-infrared light is almost totally absorbed by water, the ERTS near-infrared channel (that is, channel 7) can be directly sliced to isolate those pixels obtained on open water surfaces. The general scheme is illustrated in fig. 46. The ERTS digital record of radiance values in channel 7 shows a sharp and significant change between "water" pixels and "land" pixels. A threshold value is chosen that is well below the "land" radiance value, but above the "water" radiance values. A computer program then eliminates all radiance values above the threshold value, and assigns a code indicating "this is a water pixel" to all values below the threshold. The result is a new digital record of all "water" pixels. The result is a relatively simple and elegant method of mapping open water surfaces.

We do not mean to imply that the procedure is infallible. It is not. For example, if there is haze in the atmosphere, backscattered radiation reduces the contrast between "water" and "land" pixels, and this significantly reduces the reliability of the separation. Other kinds of things, like very high turbidity values in the water, may also cause difficulties. Despite such problems, the technique has proven to be very useful indeed.

It must not be assumed that the only way to extract information from remote-sensor products is by way of digital processing. To the contrary, digital processing techniques are still quite highly specialized and experimental. Far more information is currently extracted from remote sensing products by what might be called classical

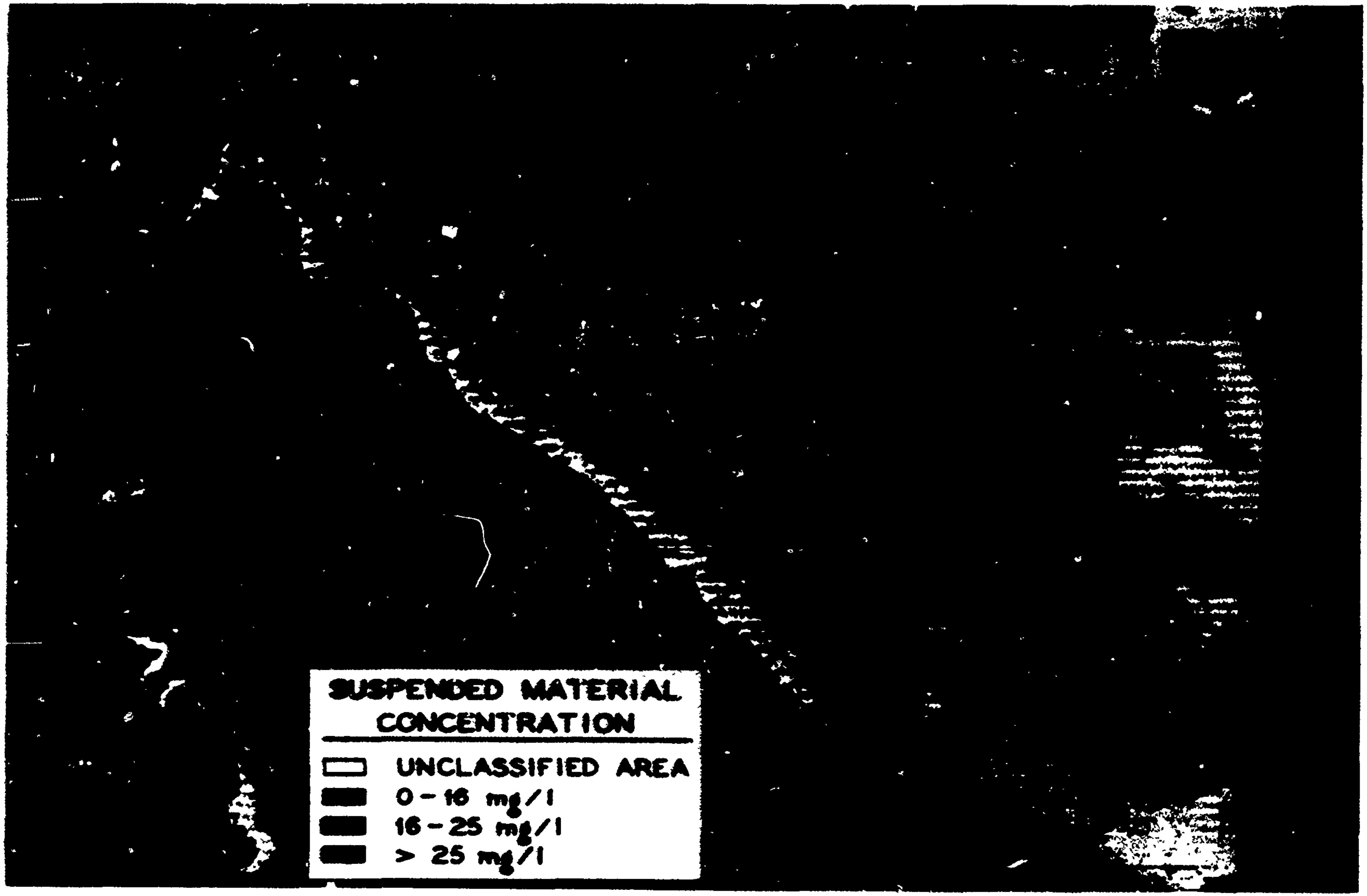


Fig. 45. Example of picture derived from digital data

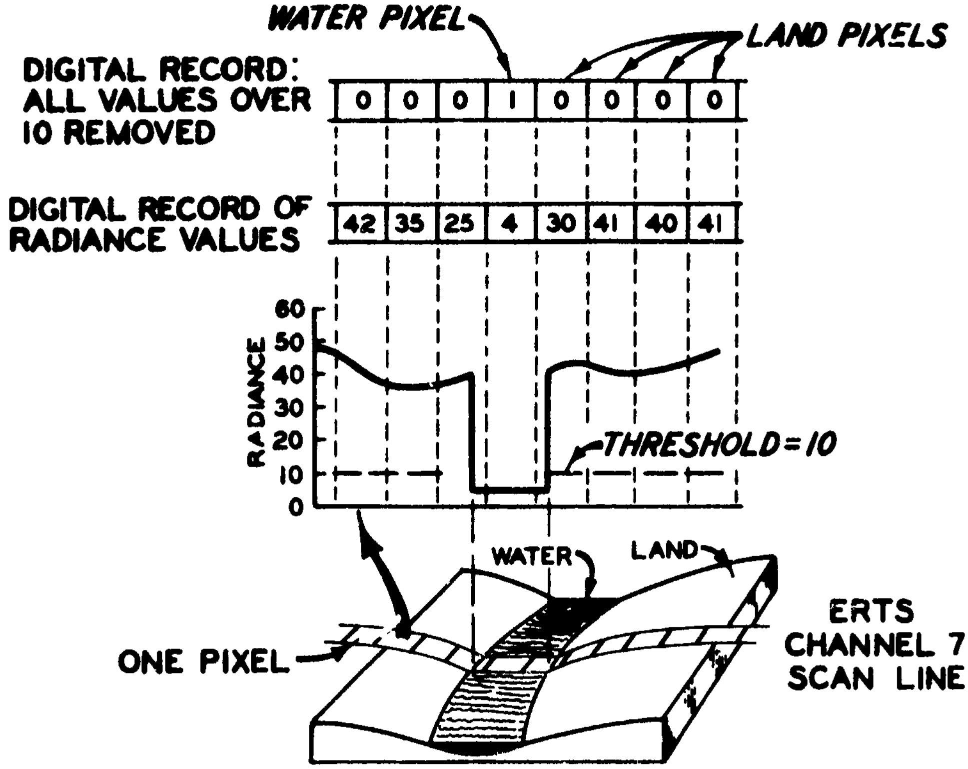


Fig. 46. Water pixels versus land pixels

photointerpretation methods than by all other procedures combined. In view of this, direct interpretation of hard-copy images (that is, pictures) should not be overlooked.

Photointerpretation is the primary current method of extracting information from pictures because the human mind can integrate and draw conclusions from incredibly sparse and unorganized sets of information. We cannot program a computer to do the same thing because we do not understand the process by which the human interpreters sort out the trash and find the grain of fact. So the human interpreter is going to be around for a long time.

This illustration (fig. 47) consists of a picture of a chenier in the Mekong Delta and a similar feature in the Mississippi River Delta. A chenier is an old sand beach ridge surrounded by swamp or marsh deposits: Any scientist with photointerpretation training can quickly recognize the basic feature, despite local differences in land

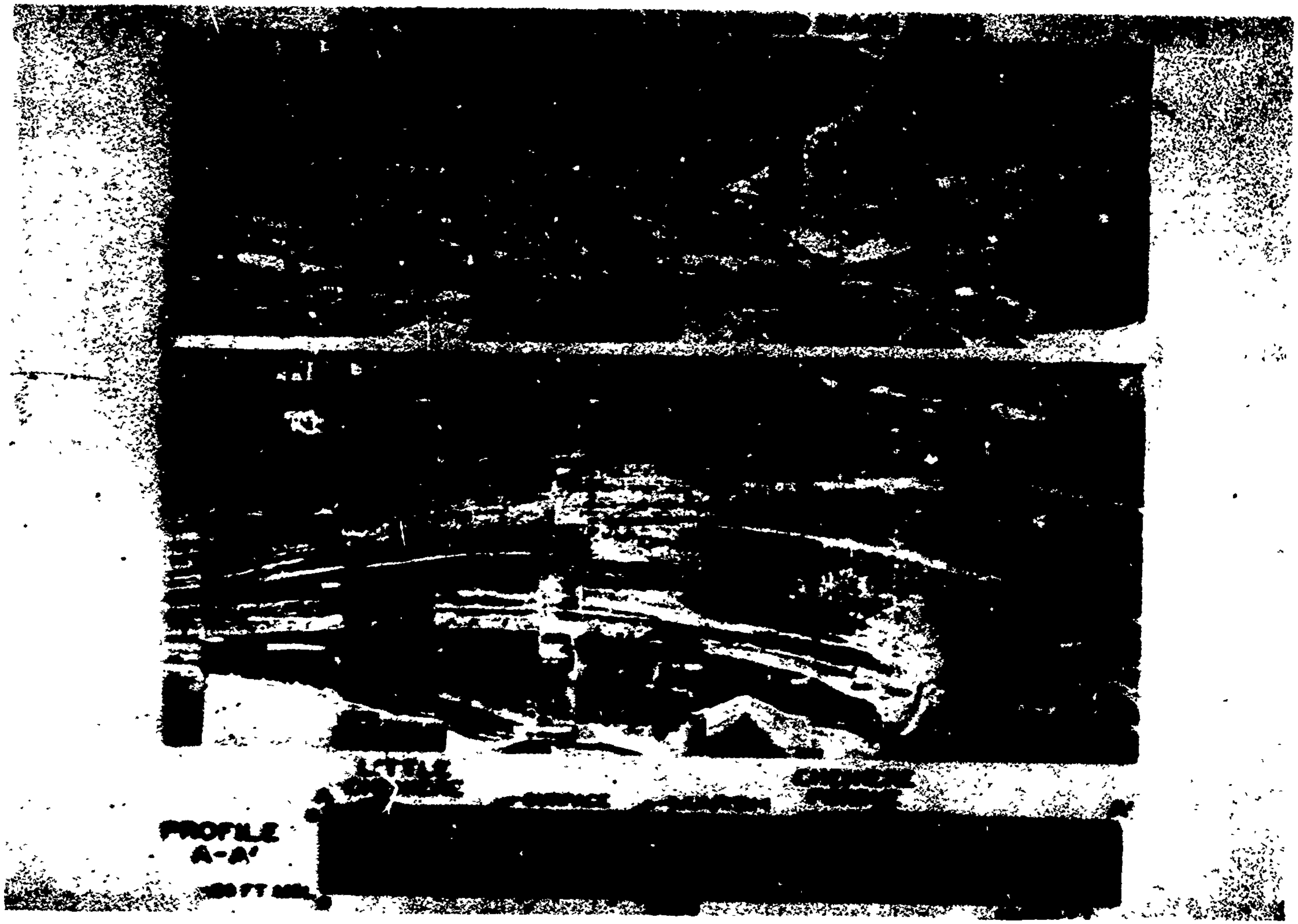


Fig. 47. Depositional type determined by remote sensing

utilization, cultural practices, and so on. Somehow, by processes quite mysterious, he is able to filter out the "noise" in the images and identify the cheniers. Having identified the feature, he can say with considerable confidence where sand could be found in this landscape and where the soil will be silt or clay. All of this, despite the fact that the two pictures really don't look very much alike, at least to the untrained eye.

Let us present another example, this time using an image formed with a thermal infrared scanner (fig. 48). You will note that the image is a mosaic made by assembling the products of three separate flight lines, flown only a few moments apart. In theory, a thermal infrared scanner measures the temperature of the thing being imaged. But if this is so, one may well ask why adjacent strips exhibit such widely different densities. It is obvious that the temperatures did not change so dramatically in the few minutes between passes. There may be a number of reasons for such anomalous data, but in the case of a thermal infrared sensor, the most probable reason is that the scanner operator changed the gain settings on the instrument between passes. The result is that the data are more-or-less completely useless for objective analysis. Thus, despite the intention to correlate density of image with ground temperature, and thus objectively evaluate heat fluxes in the surface soil, the analysts were forced to fall back on purely subjective analytical procedures.

The point to be made here is that control of every detail of a mission utilizing a remote-sensor system is absolutely essential. Under certain circumstances, even a small change in mission profile, like changing the setting on a single control dial, can force a major change in information extraction procedures, or even, in extreme cases, wipe out the entire effort. In this instance, the original intent was to extract information about absolute temperatures, so that a temperature isopleth map could be constructed. The failure to control the mission profile made that objective impossible to obtain; instead, the information that could be extracted was degraded to qualitative inferences of cool versus warm areas. The philosophical point to be made is that a

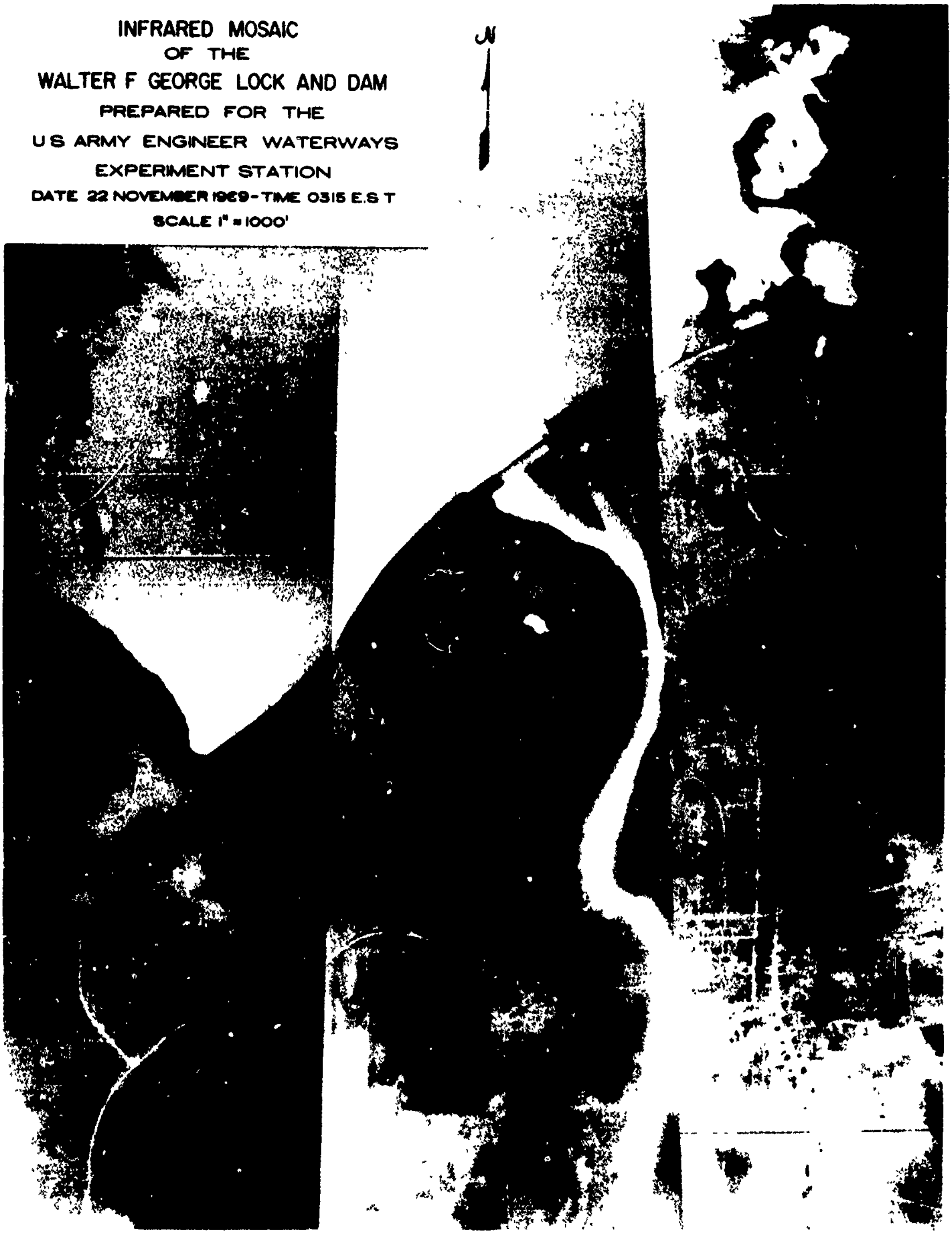


Fig. 48. Image formed with thermal infrared scanner

human interpreter, using subjective techniques, was able to wring information out of the remote-sensor products, even though automated and objective processes had failed.

Information on "hard" cultural features, like roads, bridges, buildings, land use practices, and so on, is among the easiest to obtain by conventional image interpretation. It is often assumed that such information can be obtained from maps, but in a rapidly changing environment this is usually not the case; the map is obsolescent by the time it comes off the presses. Problems requiring data on cultural features are often such that considerable detail is required, and this requirement usually translates into a specification for very sharp air photos at quite large scales. The type of film is sometimes not critical, but the most widely used are panchromatic, false-color infrared, or (as in fig. 49) standard color. It should be noted also that the picture is an oblique; such images are often more useful for certain purposes than the more conventional vertical views.

There are a number of devices that have been designed expressly to aid the photointerpreter. These include such things as the stereoscope. This basic gadget comes in a lot of models, from simple little optical instruments that can be carried in the shirt pocket to quite sophisticated devices. The illustration (fig. 50) shows one of the more elaborate, an Old Delft stereo viewer. With this device the interpreter can use several different magnifications, optically rotate images for ease of positioning, and so on.

Another standard device is really only a somewhat elaborate light table (fig. 51). This one handles rolls of film transparencies and comes equipped with a built-in stereo viewer and some other niceties. There are some significant advantages in using film transparencies as opposed to conventional prints, the most obvious is that the granularity of the images is reduced, which means that the effective clarity of the images is improved.

A not-so-standard device is the additive color viewer (fig. 52). This device will take four film transparencies, such as those obtained with an I^2S camera, and optically bring the four images into accordance.

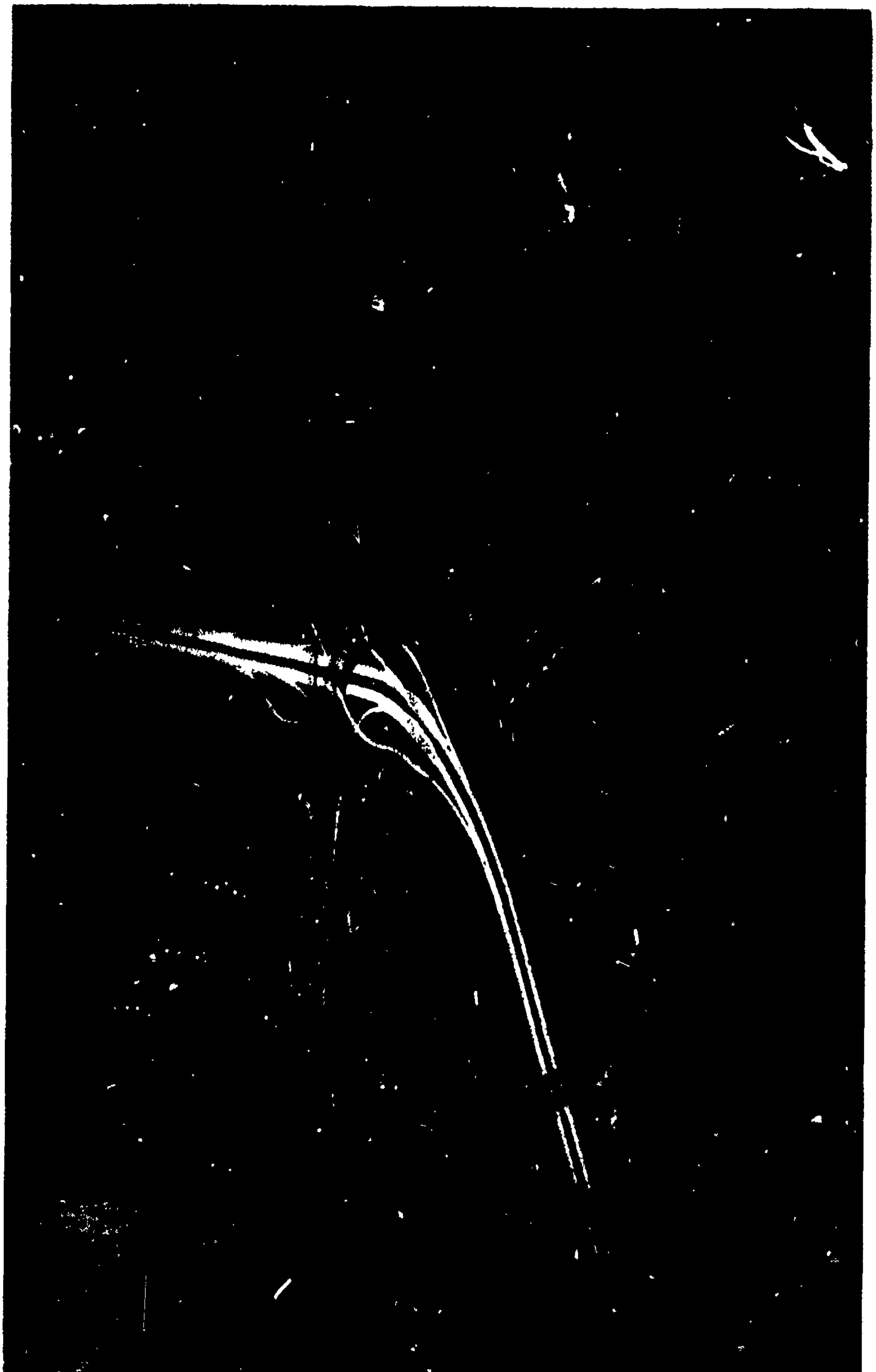


Fig. 49. Highway interchange near Dallas, Texas.
(Original on standard color film)

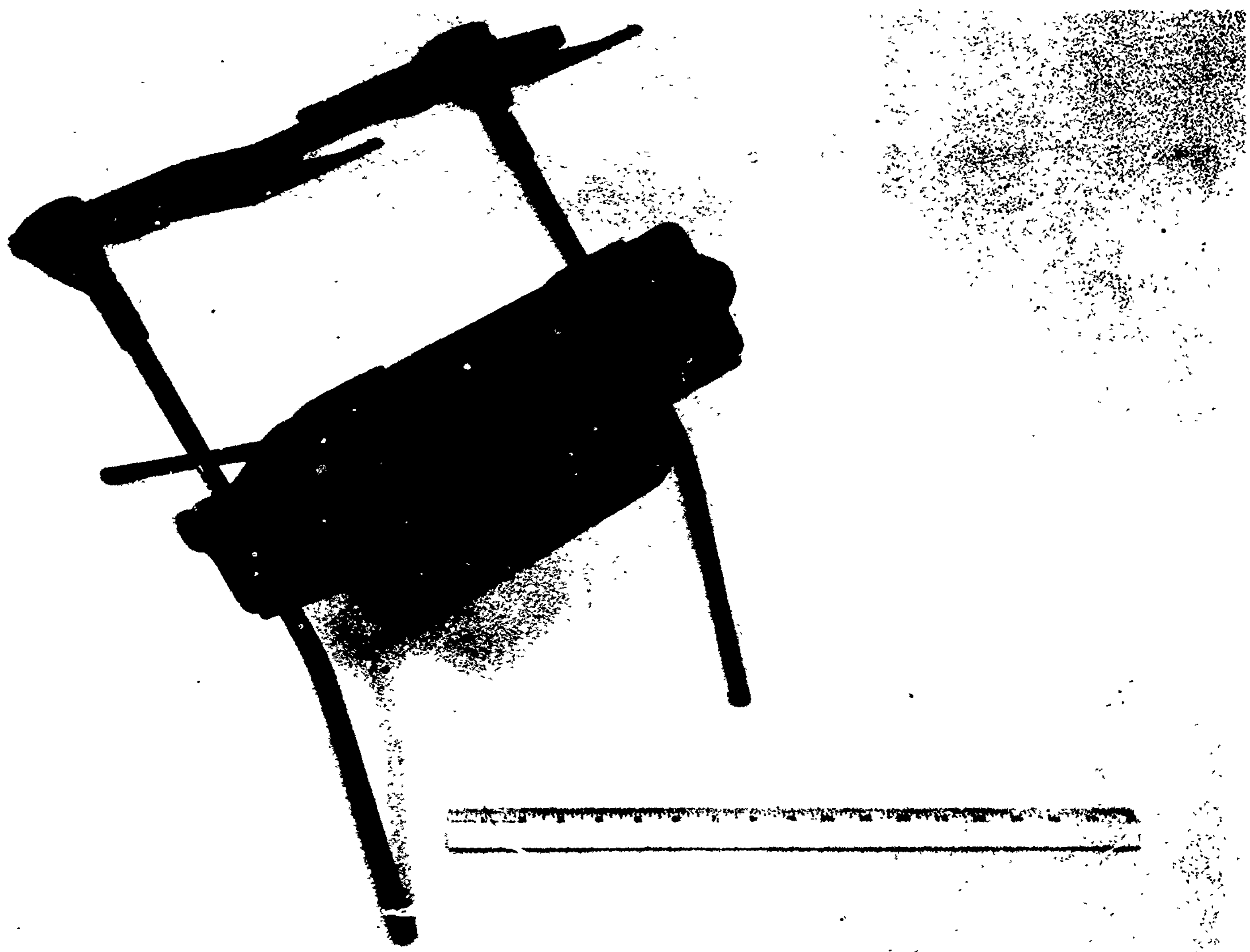


Fig. 50. Old Delft viewer

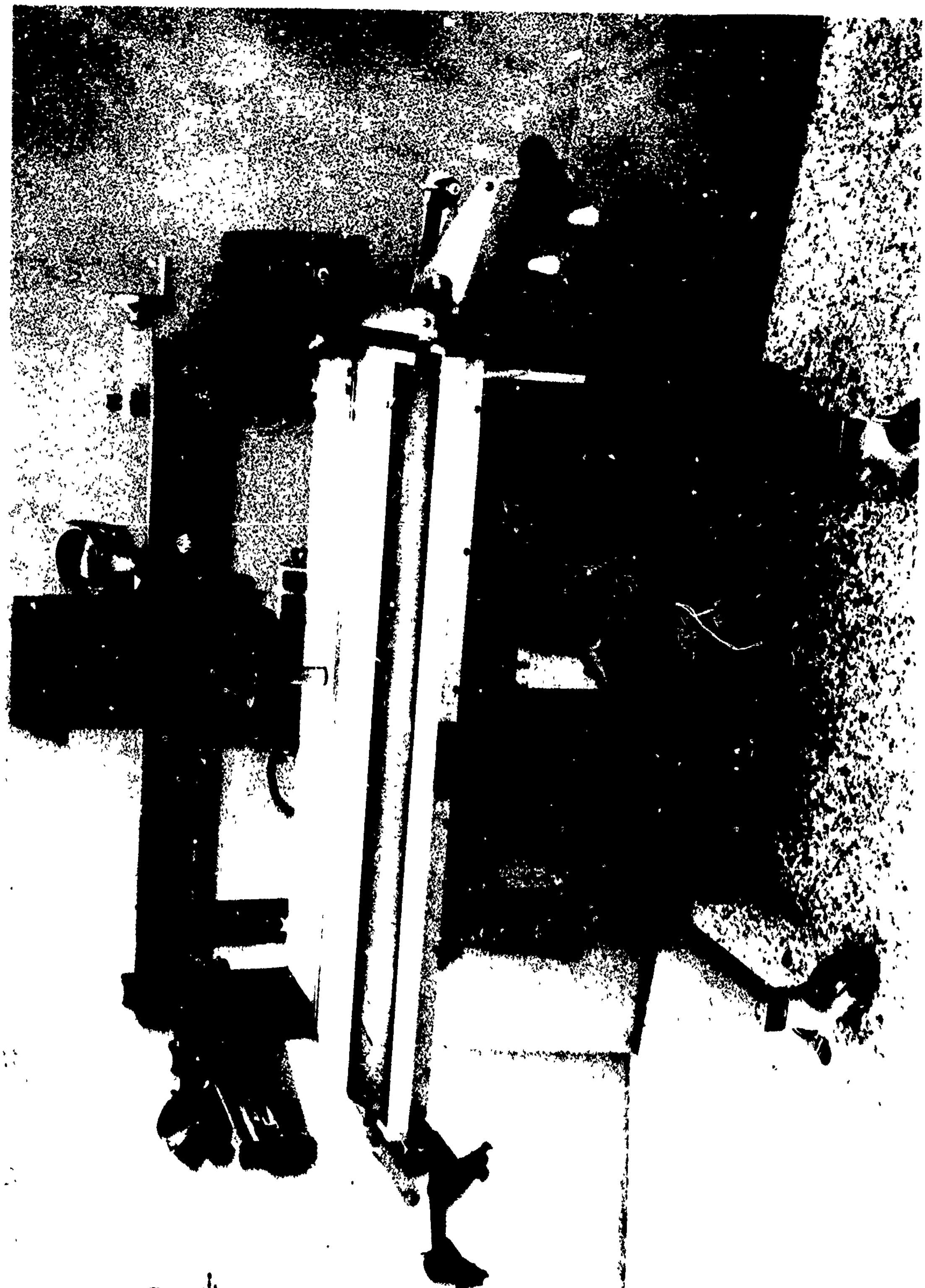


Fig. 51. Light table

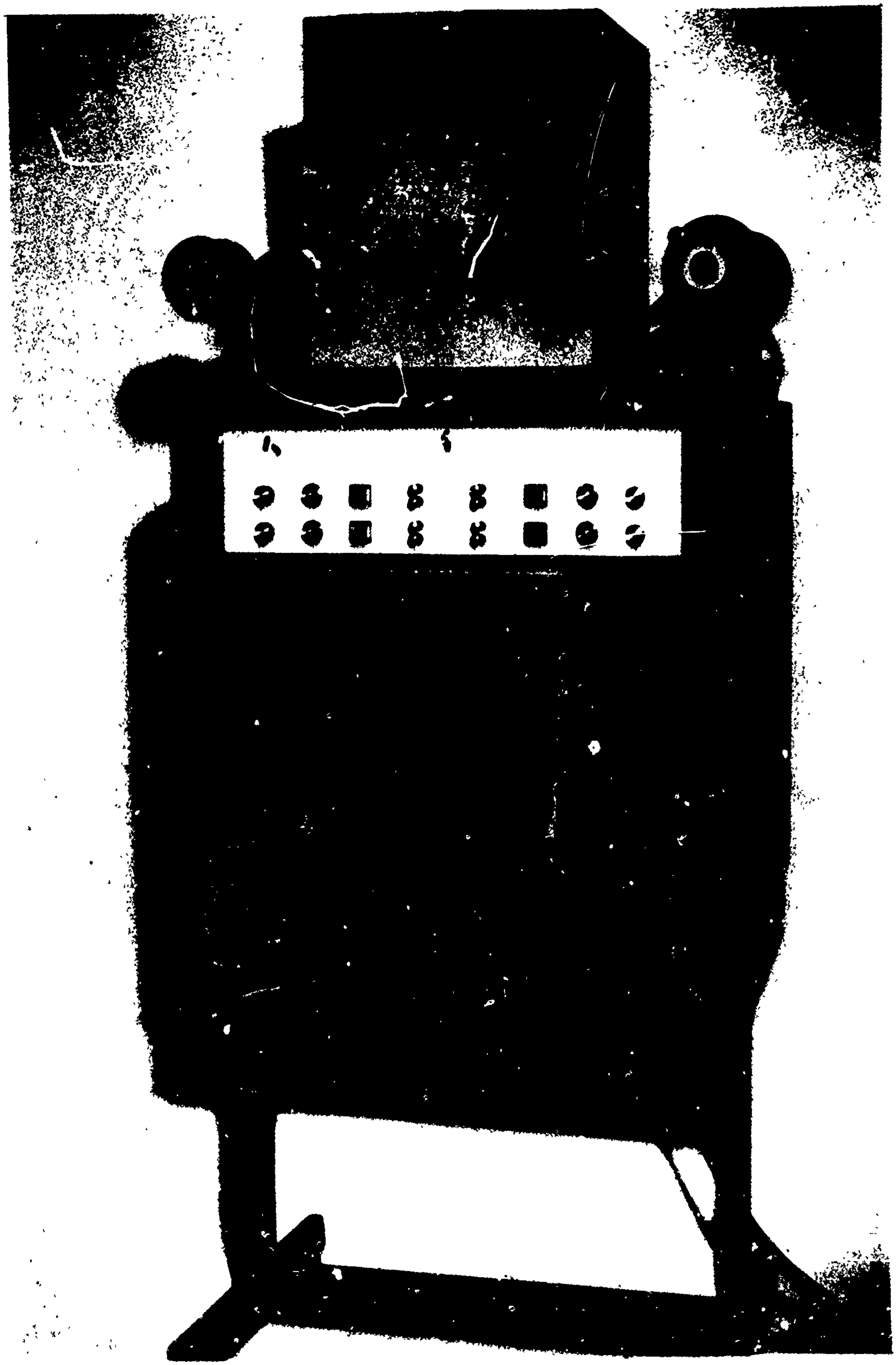


Fig. 52. Additive color viewer

One can then assign a color to each image, and thus reconstitute a color image out of as many as four black-and-white images. The colors may be varied in intensity. A skilled operator can use this gadget to effectively interpret multispectral images, which is no small trick.

Finally, remote-sensor systems can be used to obtain metric data. Given stereopairs, which are really nothing more than two images of the same area taken at the same scale from slightly different positions, almost any property inherent in the three-dimensional geometry of the scene can be measured. For example (fig. 53), one can draw contours of the topographic surface, measure the heights of trees, buildings, or bridges, measure the areas of lakes and fields, and so on. The most common, and one of the most useful, devices for obtaining such data from air photographs is the Kelsh plotter (fig. 54).

- **TOPOGRAPHIC CONFIGURATION**
- **HEIGHTS OF OBJECTS (TREES, DAMS)**
- **AREAS OF OBJECTS (LAKES, FORESTED AREAS)**

Fig. 53. Example of three-dimensional data that can be obtained by remote-sensor system

If the objective is to obtain reliable metric data, several things must be kept in mind:

<u>a</u>. The images must be very sharp; reliability of measurement is directly related to the sharpness with which the edges of objects are portrayed.

<u>b</u>. The scale of the image must be large enough to permit a measurement of the item of interest. One way of keeping this in mind is to remember that a standard 28-ft pavement is less than 0.5 mm wide on a photograph with a scale of 1.20,000. In practice, this means that to even <u>roughly</u> approximate the width of the roadway by measurement from the photograph requires the ability to measure distances of about one one-hundredth of a millimeter. This is very hard to do. The best measurement device for such purposes is the Comparator (fig. 55), which in theory will measure distance as small as one one-thousandth of a millimeter. In practice, it is not quite so good.

<u>c</u>. The image must have enough contrast between the object being measured and the area around it so that the edge is easy to see.

Fig. 54. Kelsh plotter

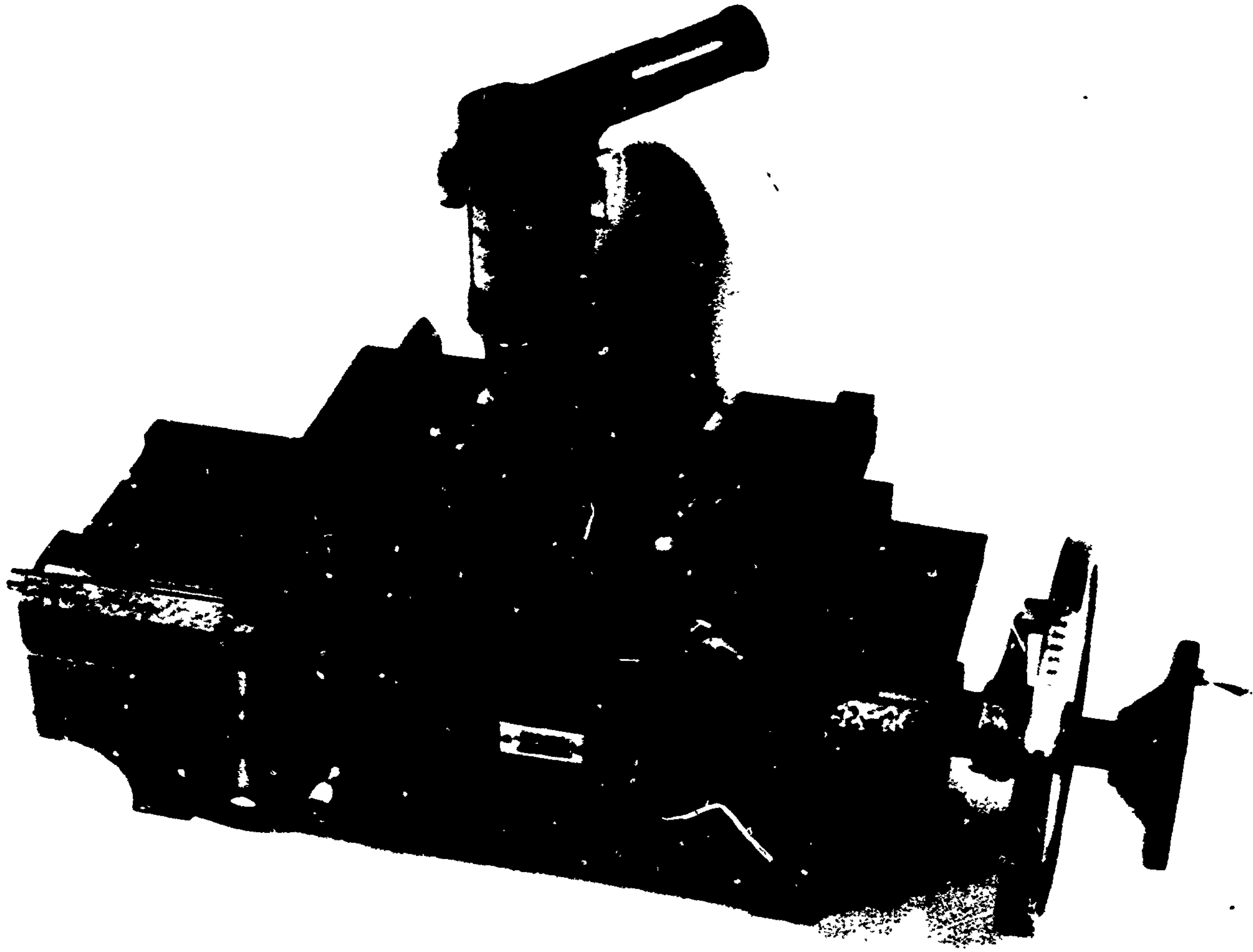


Fig. 55. Comparator

A word of caution. It does very little good to enlarge a photograph, hoping thereby to make things easier to measure. The reason is that the edges get fuzzy faster than the image expands, and so the accuracy of boundary identification quickly degrades.

Information presentation

Having obtained the information or data that was the objective of the remote-sensing exercise, there is often a tendency to relax and assume that the mission has been accomplished. However, there is one more essential step, namely that of putting the acquired data into a form such that it can be readily used for the purpose in hand. For example, suppose the objective was to determine the configuration of channel segments along a large river. Let it be further assumed that it would be possible to obtain stereo-imagery of them at appropriate scales. We can then imagine analysts obtaining an array of elevation points of the above-water portion of the channels by photogrammetric processes. Below-water elevations might be obtained by sounding. At this point they have in hand all of the data they were after. The difficulty is that those data are not in a form that makes them easy to use. Perhaps the people who want the data want a number of closely spaced cross sections, or perhaps they want a contour map (fig. 56). The illustration shows a contour map of a side channel on the Mississippi below St. Louis. The data were obtained by using two remote-sensing systems in conjunction: a sonic depth-finder (which is, you will recall, a line-scanner system), and stereophotographs at a scale of 1:1000. The sonic depth finder provided data for constructing the below-water configuration, and photogrammetric procedures were used to obtain data for the construction of the above-water configuration. The data from both sources were utilized by a computer program that automatically constructs contour maps using random arrays of XYZ coordinates. These data are now in a form in which they can readily be used, and so the job of the remote-sensor types has at last been concluded.

Let us look at some other kinds of products, produced by remote-sensor analysts, for various purposes. A relatively new product, computer-drawn from the same data files used to generate contour maps,

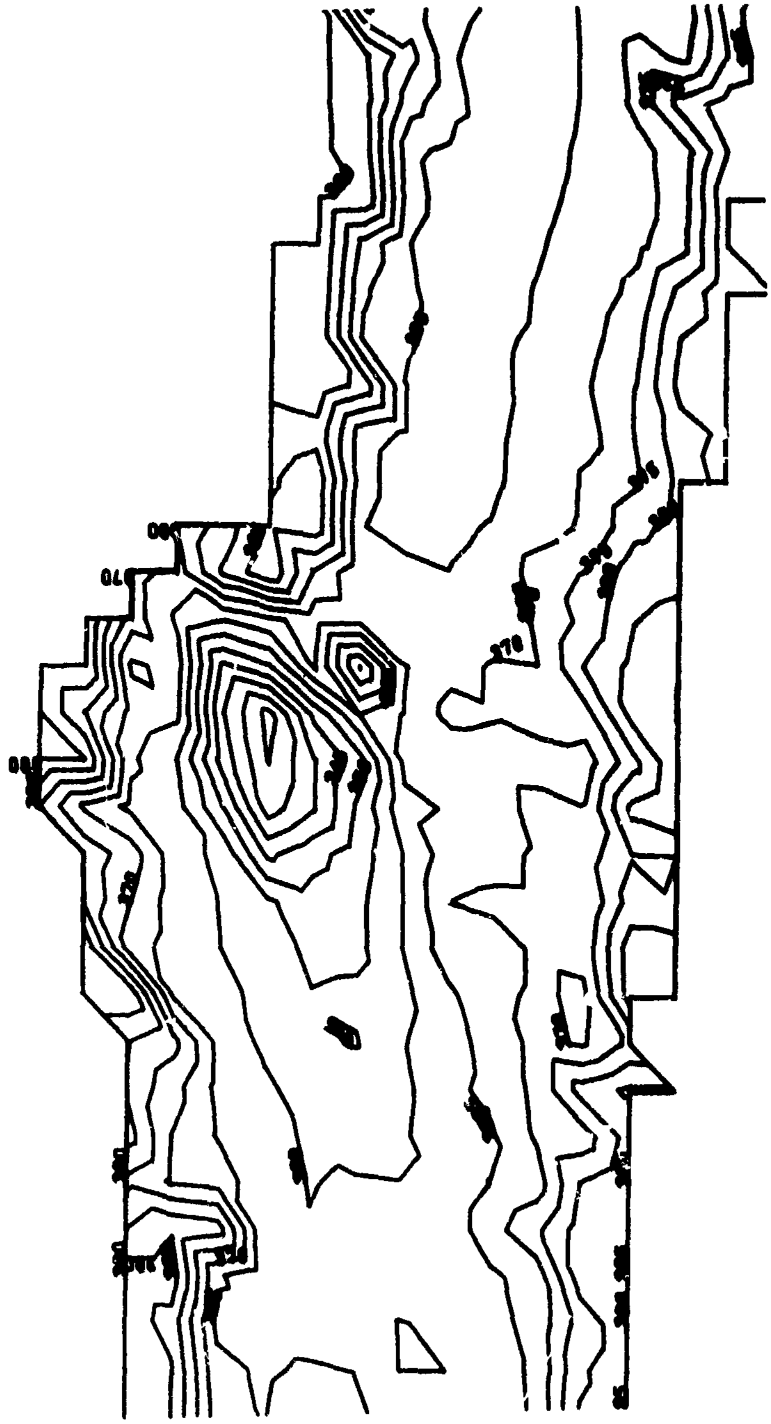


Fig. 56. Computer-generated contour map

is the block diagram (fig. 57). It is, as you can see, composed of a number of closely spaced cross sections. This kind of product has proven to be very useful to people who plan recreation facilities, scenic roadways, and even things like flood-control systems. In at least one instance, they have been used for public relations purposes to show how a landscape would look before and after modification.

Distribution maps are also very useful. For example, the Mississippi River Commission and the Lower Mississippi Valley Division were very much concerned with the distribution of floodwaters during the 1973 flood. This illustration (fig. 58) shows the extent of the flood on a reach of the river below Memphis, Tennessee. It was generated by using the density-slicing technique, which was described earlier, on ERTS data obtained during the height of the flood. The map was drawn entirely by computer processes directly from NASA digital tapes.

Sometimes it turns out that a map alone is not enough; instead, what is required is an interpretation of some property of a map (or, more properly, of the terrain represented by the map). The unshaded area in this map (fig. 59) is the area visible from the point marked by the asterisk at the lower left corner. This interpretation of topographic data was drawn automatically by the WES computer and an incremental plotter. This routine might be quite useful, for example, for optimizing the location and height of a fire tower or positioning a scenic overlook in a recreation area.

In these days of concern with environmental problems, remote-sensor data users are often faced with the problem of mapping distributions of very complex associations. For example, a relatively common requirement is for maps showing the associations of soil types, topographic slopes, and vegetation types, because specific animal and plant species tend to occupy habitats or ranges characterized by specific combinations of these factors. It thus often develops that the planners ask for maps showing distributions of complex factors. Many of these factors may be interpreted from remote-sensor data. For example, a skilled interpreter supplied with adequate ground control can often discriminate among even very subtle differences in vegetation and soil

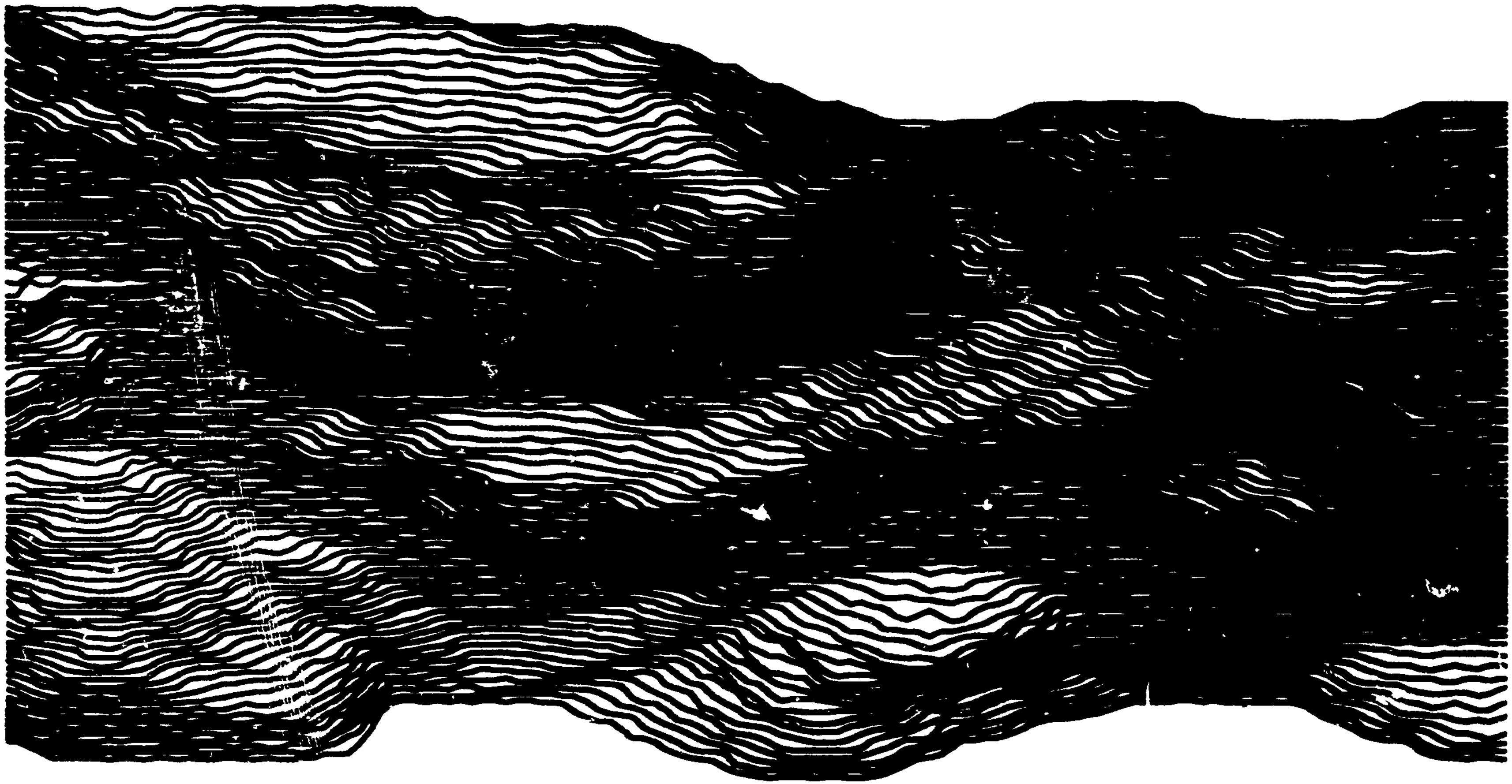


Fig. 57. Computer-generated block diagram

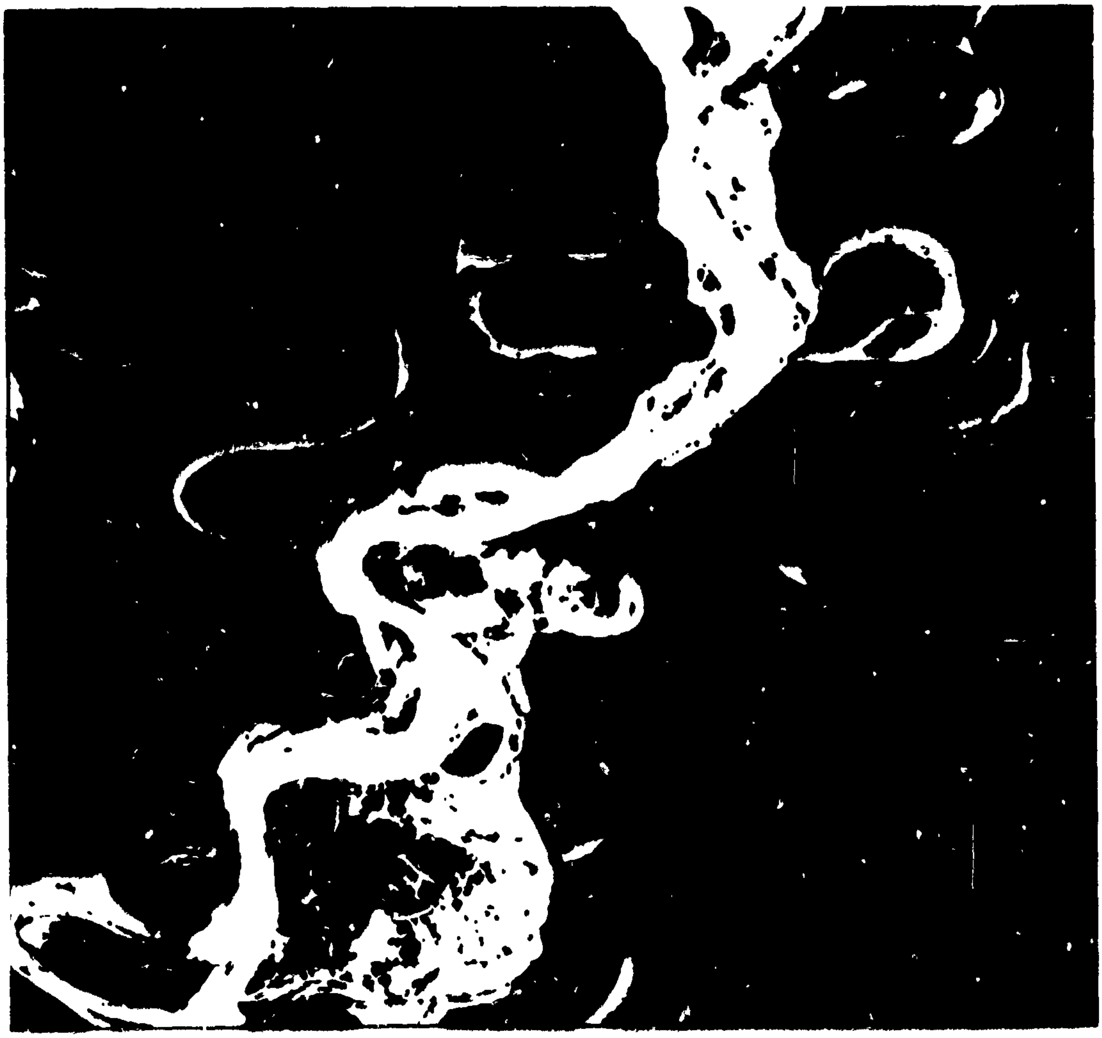


Fig. 58. Sample overlay of flood in Lower Mississippi River Valley

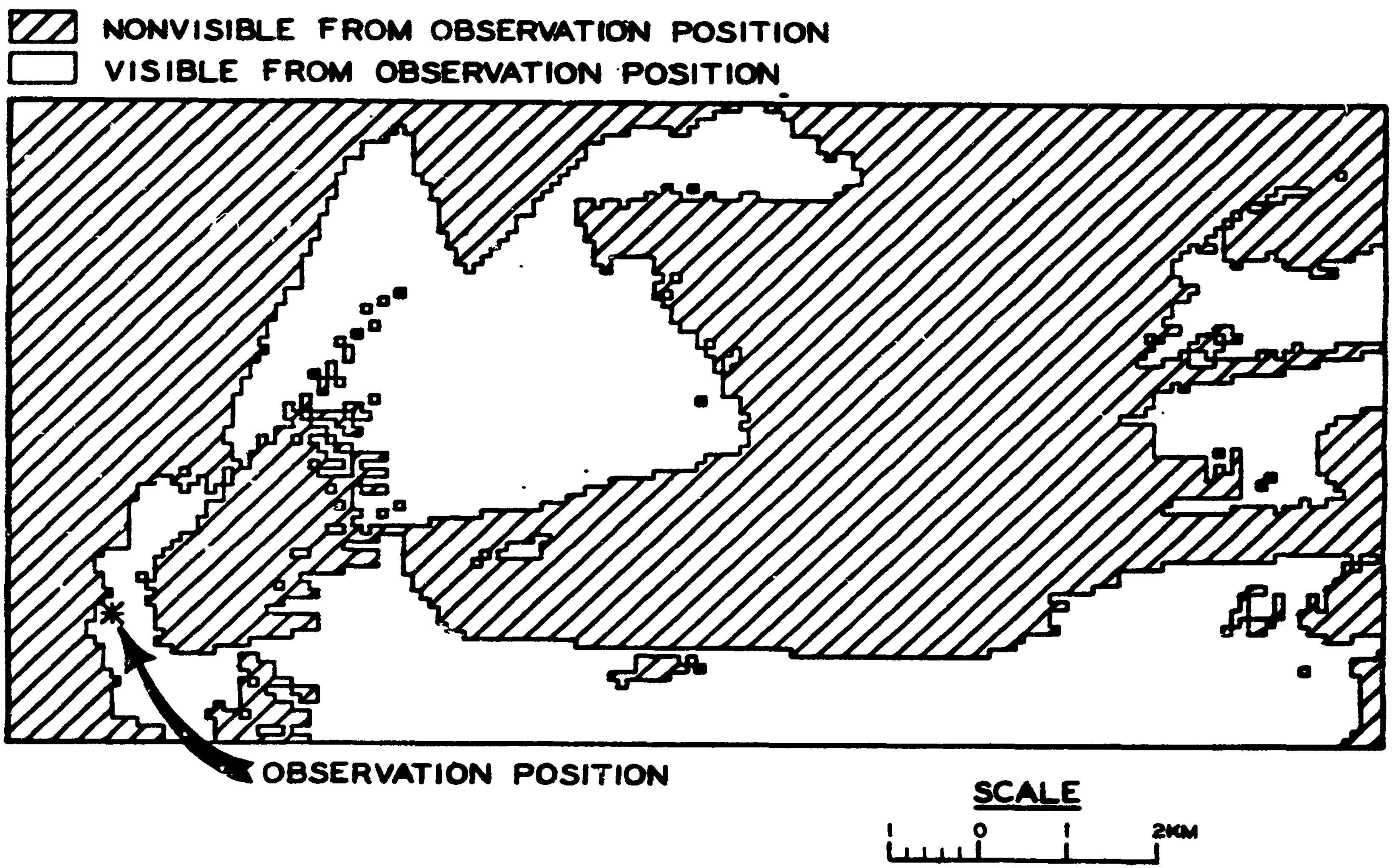


Fig. 59. Line of sight map

types and thus can effectively map such characteristics of the terrain. The problem sometimes comes when he is asked to put all of the maps together to show the specific locations of patches of ground characterized by a particular forest type, slope class, and soil type. This illustration (fig. 60) shows the general principle involved: the three factor maps (basal area, which refers to a characteristic of vegetation, slope, soil strength) are "stacked" to produce the factor complex map. This process, which looks so simple, is actually very exacting and time consuming, and therefore expensive. Yet, it is often essential to the solution of ecological problems. Fortunately, the WES has had to produce such maps many times in the past, and some quite elegant routines are available for achieving the compilations.

Maps showing time sequences are often helpful, especially in urban planning. It is often possible to find airphoto sets spaced in time but covering the same area. With such sequences a skillful interpreter can map land-use types, the distributions of "hard" cultural features (as was done to produce this map of a part of Fort Belvoir (fig. 61), and so on. The difficulty is that only rarely will all sets of imagery be at the same scale, and never will they have the same degrees of tilt or other distortions. The remote-sensor data analysts are thus faced with major problems of rectification and scale adjustments. Until very recently, the procedure was to adjust the photo scales to a common value by enlarging or reducing the photos and transferring annotated data on the resulting photos to maps by the old tried-and-true "eyeball method." There were two problems. First, the rephotographing process degraded the quality of the pictures and thereby reduced the reliability of the interpretations or analyses. Second, the "eyeball method" of transferring data is notoriously inexact and inefficient.

A far better method is now available. The procedure is to work directly on the available photos, regardless of scale or distortion. The annotations are then transferred to a computer file by a digitizer (fig. 62). A computer program then mathematically adjusts the scale and corrects distortions, so that all of the pieces fit together. This procedure was used to bring diverse data sources into accordance to

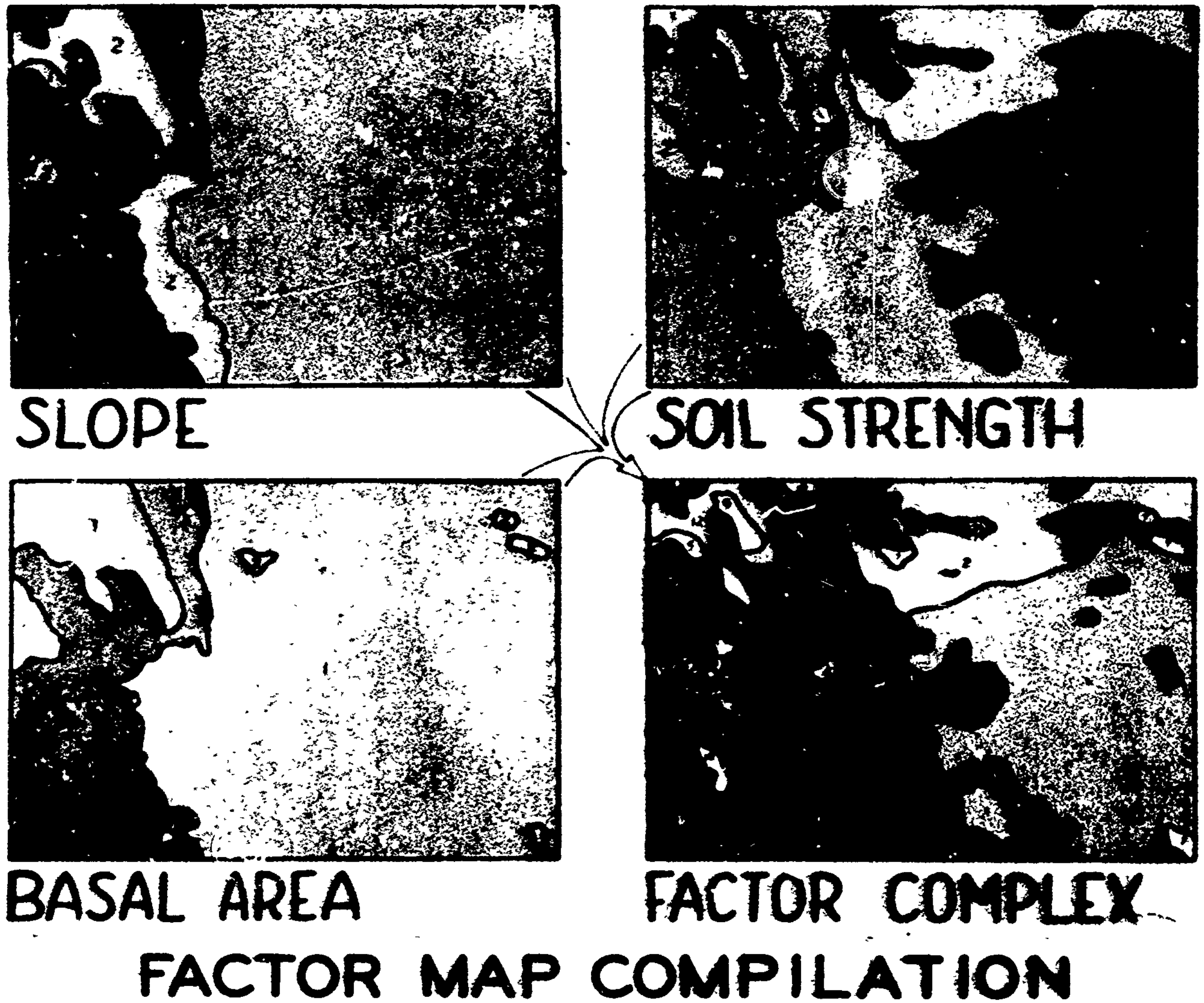


Fig. 60. Principle of factor complex map

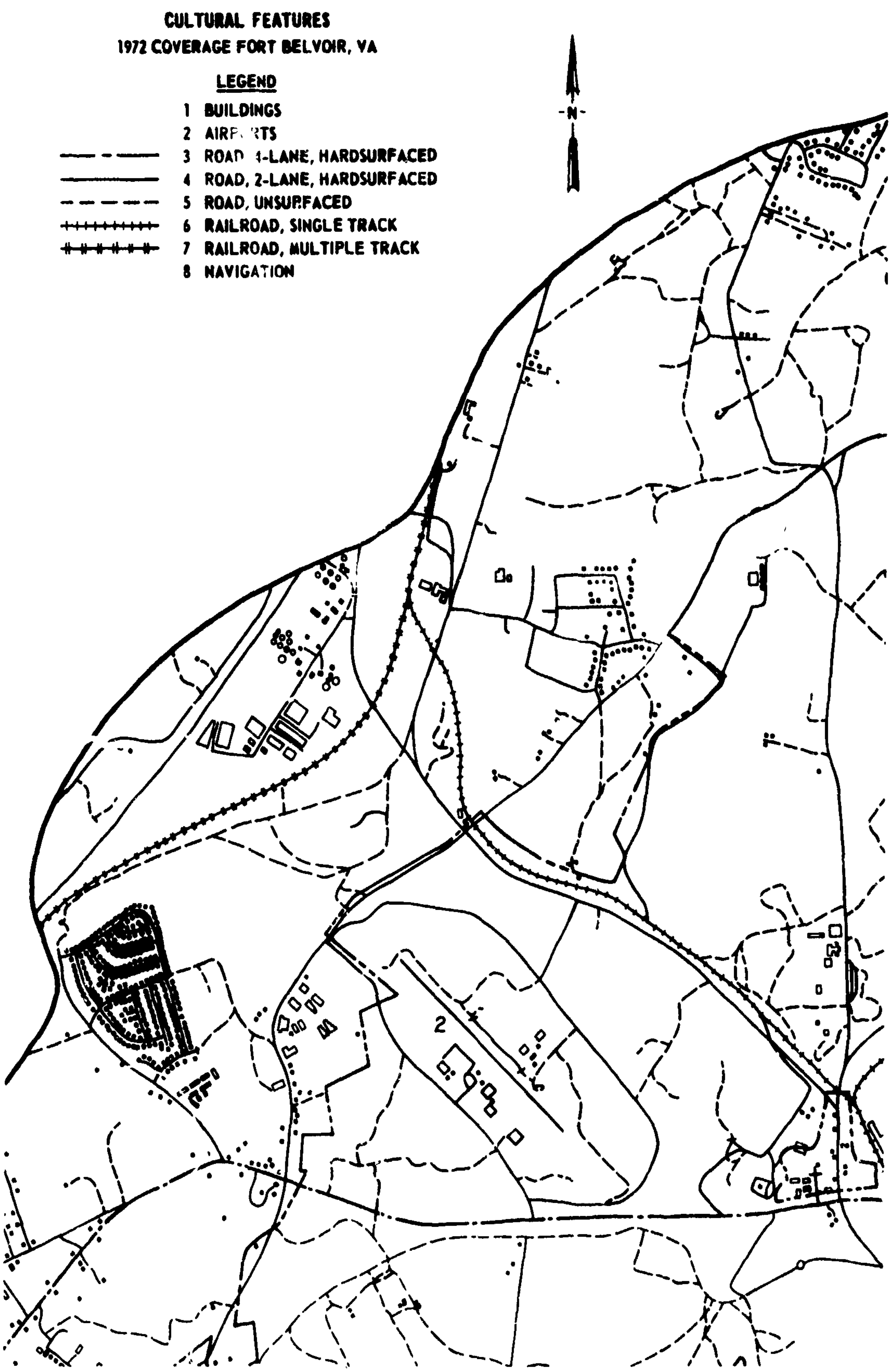


Fig. 61. Map showing distribution of cultural features

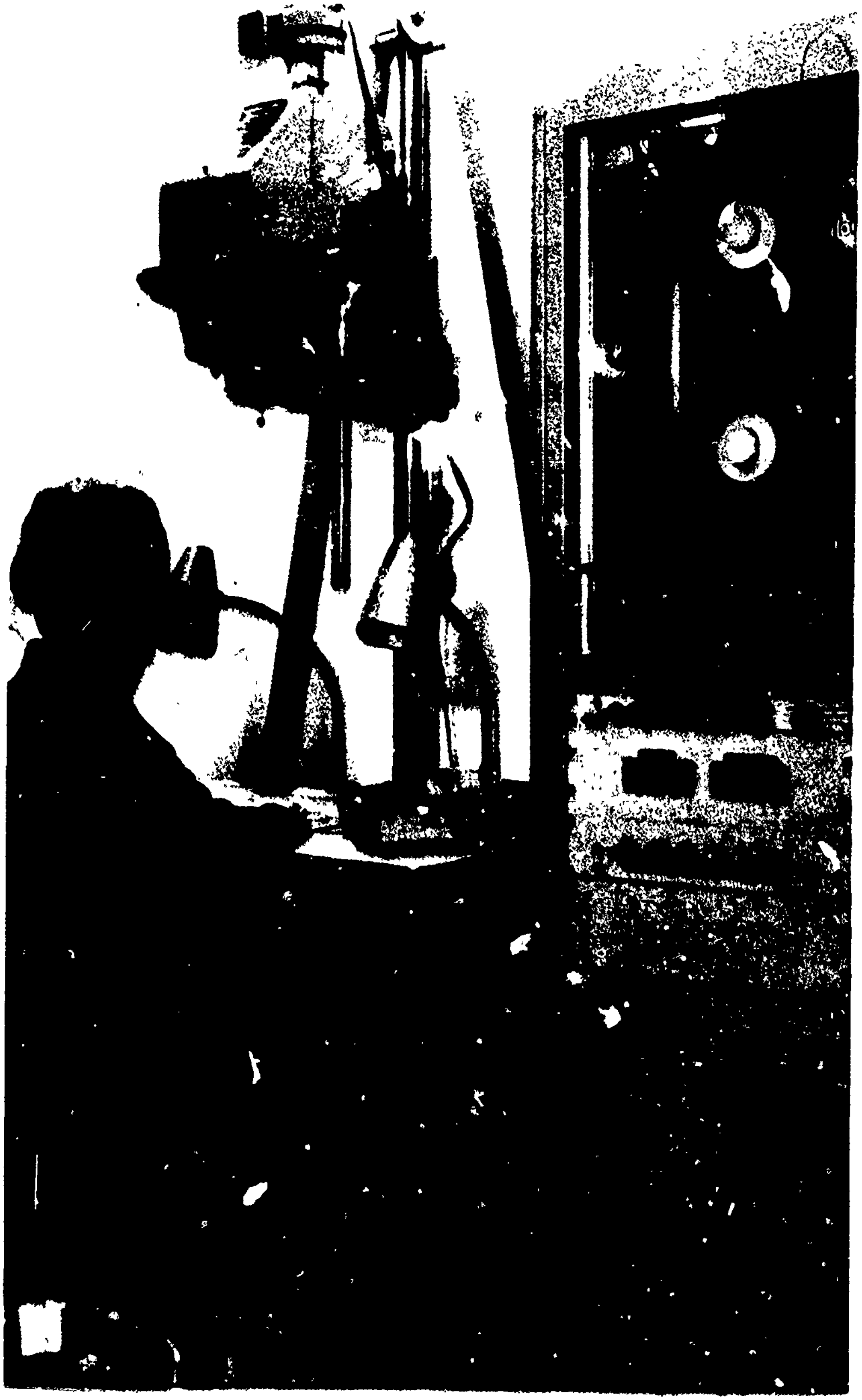


Fig. 62. Example of a digital converter

produce this map (fig. 63) of the sanitary sewer system of metropolitan Chicago.

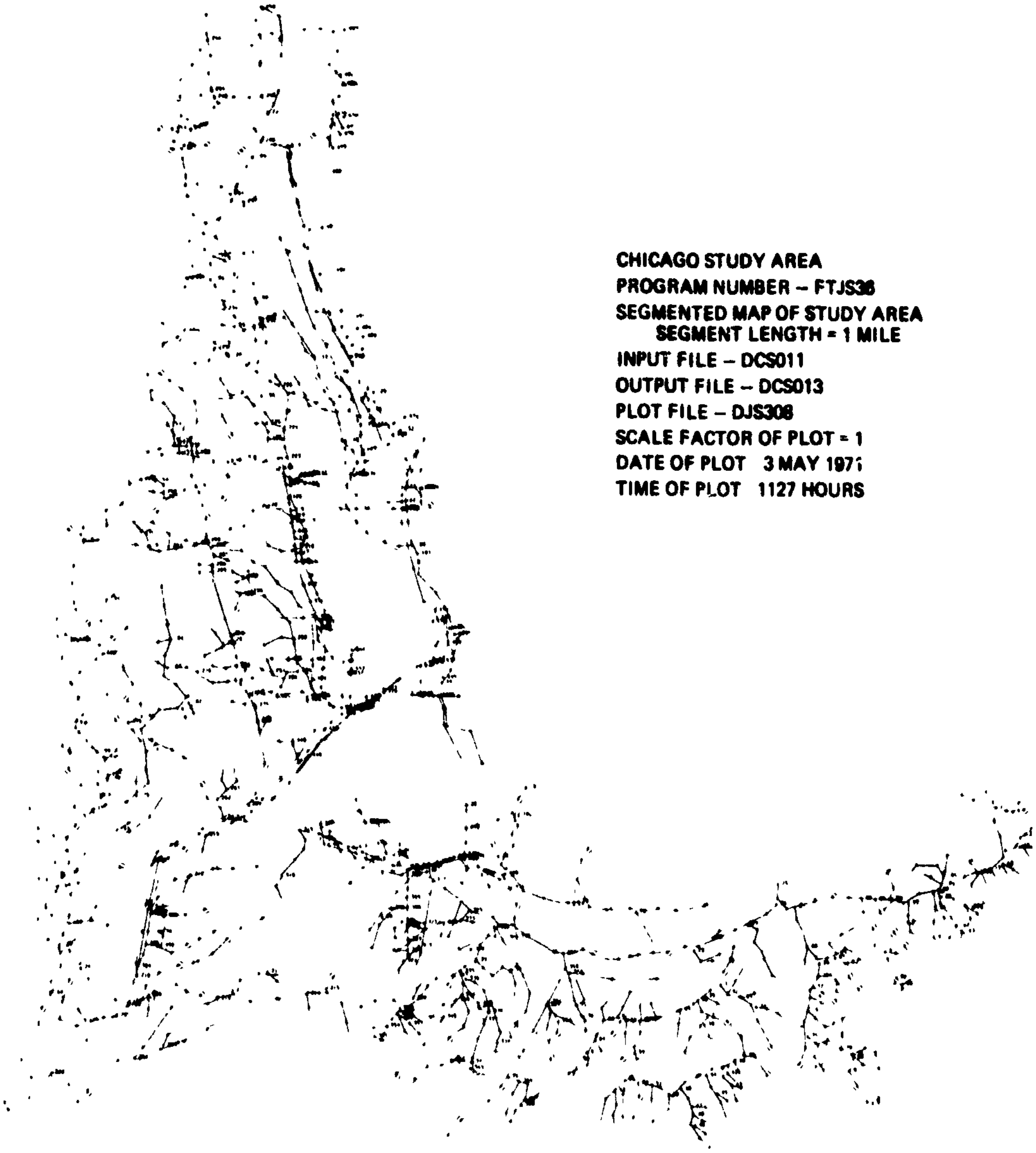


Fig. 63. Map produced from diverse data sources

Finally, while it may not properly be their thing, remote-sensor users sometimes get drawn into the business of developing the problem solution itself. This quite often happens because the process of data identification, information acquisition, information extraction, and data formatting become so inextricably tangled with the problem analysis that everyone loses track and each person does whatever is necessary to solve the problem. And so we find remote-sensor users preparing files for and writing programs to use data which may have been acquired only in part by remote-sensing systems. Here (fig. 64), for example, is a

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RUNNING TIME:     2.2 SECS    I/0 TIME :     1.0 SECS

READY
0LD:FLDST0

READY
RUNNH

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ENTER RESERV0IR NAME  ?R0WLESBURG PLAN A

 ENTER EFFECTIVE DRAINAGE AREA 0F RESERV0IR,FULL P00L
ST0RAGE, AVAIL.WATER F0R FL0W AUG.,MIN.P00L STORAGE,(AF.)
 ?936,870400,462849,9400

ENTER M0NTH,1=JANUARY,2=FEBRUARY,ETC.
 ?7

RESERV0IR CAN ST0RE 5 INCH RUN0FF
RUN0FF IN ACRE-FT=     64896.RES. N0W C0NT.    537145.AF.
RESERV0IR CAN ST0RE M0NTHLY RUN0FF
RES. CAN ST0RE    6.68  IN. 0F ADDITI0NAL RUN0FF
WATER AVAIL. F0R FL0W AUG. IS    527745.ACRE-FT.

RUNNING TIME:     2.1 SECS    I/0 TIME :     1.4 SECS

READY
0LD:FL0W

READY
RUNNH

ENTER N0. 0F RESERV0IRS,WATER AVAILABLE F0R FL0W AUG.(AF)
 ?1,527745

ENTER M0NTH AND YEAR F0R WHICH FL0W AUG. IS T0 BE
 C0NDUCTED, 1=JANUARY ,ETC., 1=1975, 2=1985,ETC.
AND EXCESS V0LUME DISCHARGE RATE (CFS)
 ?7,3,0

THE DISCHARGE RATE F0R RES. 1  IS    2201.60CFS
WATER REMAINING AFTER FL0W F0R RES. 1  IS    396741. AF.
RES.1  IS DRAWN T0 MIN. P00L IN 120.08DAYS
THE FL0W REQUIREMENT IS MET F0R YEAR,M0NTH        3        7
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Fig. 64. Record from conversational mode computer program

record of a conversational mode computer program that was written to solve some problems relating to the positioning and characterization of a set of flood-control and water-quality storage reservoirs in West Virginia. Some, but by no means all, of the data in the files that drive this program came from remote-sensing systems. But the sensor users helped write the program.

State-of-the-Art

By now, it must be apparent that successful use of remote sensors requires considerably more than just "taking some imagery" or "flying an area." We have defined six essential processes that must be accomplished if use of a remote-sensing system is to result in useful information--problem specification, ground control data acquisition, remote sensor information acquisition, data manipulation, information extraction, and information presentation. Identification of these processes is the result of a great deal of experience at the WES in the remote-sensing "school of hard knocks."

A number of sensor types have been introduced, some fairly common and some not so common. In addition, some devices and some information extraction and presentation techniques have been mentioned that have been found to be quite useful in connection with our projects in which remote sensors were used. The intent has been to not only provide an overview of the current state-of-the-art of remote sensing, but also to introduce some of the current remote-sensing capabilities of the WES.